Study of the Effect of Compact Fluorescent Lamp on the Acetaminophen Degradation

Abdolreza Khajehzadeh, Aida Jaberansar, Maryam Firouzi

Department of applied chemistry, Darab Branch, Islamic Azad University, Darab, Iran
Department of chemistry, Firuzabad Branch, Islamic Azad University, Firuzabad, Iran
Department of technology and engineering, Sirjan Branch, Islamic Azad University, Sirjan, Iran

ARTICLE INFO
Article history:
Received 12 October 2014
Received in revised form 26 December 2014
Accepted 1 January 2015
Available online 20 February 2015

Keywords:
Acetaminophen, Compact fluorescent lamp, Acetaminophen decomposition

ABSTRACT
In this study the effect of compact fluorescent lamp (CFL) radiation on the acetaminophen degradation was investigated. The effect of various experimental parameters such as exposure time, distance between light source and solution, solution volume, acetaminophen concentration and light source angle was studied. Also the synergistic effect of time and pH on the acetaminophen radiative decomposition was investigated. The final results showed the radiation of compact fluorescent lamp decomposed acetaminophen in the aqueous solution, and experimental parameters had significant effect on this decomposition. At the distance of 10 cm, light source angle of 45°, temperature greater than 40 °C, acetaminophen concentration of 0.001 M, solution volume of 5 mL and pH of 6 to 9, the maximum acetaminophen radiative decomposition was obtained. Based on the results of this study, we can conclude the radiation of CFL (such as low consumption lamps) is hazardous for biological components.

INTRODUCTION

A compact fluorescent lamp (CFL), also called compact fluorescent light, energy-saving light, and compact fluorescent tube, is a fluorescent lamp designed to replace an incandescent lamp; some types fit into light fixtures formerly used for incandescent lamps. Compared to general-service incandescent lamps giving the same amount of visible light, CFLs use one-fifth to one-third the electric power, and last eight to fifteen times longer. A CFL has a higher purchase price than an incandescent lamp, but can save over five times its purchase price in electricity costs over the lamp's lifetime [1]. Like all fluorescent lamps, CFLs contain toxic mercury[2] which complicates their disposal. In many countries, governments have established recycling schemes for CFLs and glass generally. The spectrum of CFL was shown in the figure 1.

The lamps consist of a tube, which is compressed to fit into the space of a standard-size incandescent light bulb. An electronic ballast is also placed in the base of the lamp. In the last decade, compact fluorescent lamps (CFLs) have been widely promoted as a key alternative to replace incandescent lamps. Some initial issues have been reported, including higher initial cost, perceived poorer light quality, shorter life than advertised, inability to dim these lamps, and difficulty in finding suitable lamp fittings. Most of these issues have been progressively addressed by the industry over the past 15 years [4].

Acetaminophen (N-acetyl-p-aminophenol; paracetamol) is a widely used analgesic/antipyretic that is routinely manufactured and sold throughout the world as an over-the-counter product [5]. When acetaminophen maintained under dry conditions, the compound is very stable at room temperature [5]. However, as shown in figure 2, at elevated temperatures and in the presence of trace moisture, acetaminophen degrades more rapidly to p-aminophenol, which subsequently undergoes additional oxidative changes [5 - 7]. Likewise, the degradation of acetaminophen in aqueous solutions is both acid and base catalyzed and degrades via first order kinetics [8–10]. The activation for its degradation under these conditions has been reported to be in the 16.7 to 18 kcal/mole range, depending on solution conditions.

Corresponding Author: Abdolreza Khajehzadeh, Department of applied chemistry, Darab Branch, Islamic Azad University, Darab, Iran
Among the body of published work are several investigations that have addressed various aspects of the thermal and photolytic decomposition of acetaminophen. Aguilar et al. described the photocatalytic degradation of acetaminophen with titanium dioxide irradiated with low energy ultraviolet light (365 nm) [1]. The results of this study indicate that acetaminophen is degraded in the order of 4% by the photochemical effect. The presence of titanium dioxide in optimal amounts increases the rate of reaction and the overall conversion.

The thermal degradation of acetaminophen is studied via conventional accelerated aging studies by initially thermally stressing the compound at temperatures between 160°C and 190°C and measuring the rate of decomposition by reversed-phase high-performance liquid chromatography [2]. Ming-Chun Lu et al. studied the effect of Fenton reaction on the acetaminophen degradation. At pH = 3, increasing the Fe²⁺ and H₂O₂ concentrations leads to increase on the hydroxyl radicals which improved the degradation efficiency of acetaminophen [3].

Also the degradation and transformation pathway products of acetaminophen were studied in soil and waste water by J. Gan et al. [4]. A total of 8 intermediates were identified, including 3-hydroxyacetaminophen, hydroquinone, 1, 4 benzoquinone, N-acetyl-p-benzoquinone imine, p-acetanisidine, 4-methoxyphenol, 2-hexenoic acid, and 1, 4 dimethoxybenzene. Mineralization and rapid conversion to bound residues suggest that acetaminophen is quickly detoxified in soil, decreasing the potential for off-site transport such as leaching or runoff. On the other hand, the formation of a large number of degradation intermediates, and their potential biological activity, may pose unknown risks, such as accumulation into edible plants.

In this paper, decomposition of acetaminophen with compact fluorescent lamp radiation was studied. Effect of various experimental parameters such as exposure time, distance between light source and solution, solution volume, acetaminophen concentration, light source angle and the synergistic effect of time and pH on the acetaminophen radiative decomposition was investigated.

MATERIALS AND METHODS

Materials:
Acetaminophen (98%) was purchased from Aldrich. The stock solution of acetaminophen by concentration of 0.01 M was prepared and stored in the refrigerator. Every day, acquired fresh solutions of acetaminophen

Fig. 1: Spectrum of CFL [3]

Fig. 2: Mechanism for decomposition of acetaminophen.
were prepared from stock solution. HCl and NaOH were used to pH adjustment and purchased from Merck. Control solution was similar to sample solution except that the control solution covered with an aluminum foil.

**Instruments:**
To study the effect of low consumption radiation on the acetaminophen degradation, the very simple instrumentation of figure 3 was used. Before turn on the lamp, the system was covered with black coverage to avoid the influence of environment light.

![Fig. 3: Setup of instrument.](image)

**Results:**
The effect of various experimental parameters such as exposure time, distance, sample volume, acetaminophen concentration, light source power, light source angle, synergistic effect of temperature and synergistic effect of pH on the acetaminophen radiative decomposition were studied.

**Study the effect of time on the decomposition of acetaminophen:**
In order to study the effect of radiation exposure time on the acetaminophen decomposition, various solution of 0.001 M acetaminophen was prepared. These solutions were exposed to compact fluorescent lamp radiation for various times at 20 cm distance. Also a control solution of 0.001 M acetaminophen was covered with aluminum foil, and was placed near the sample solution. Result of absorbance difference between controlled and sample solution was shown in figure 4.

![Fig. 4: Effect of time on the absorbance difference between sample and control solution (condition: \( \lambda = 254 \) nm, distance = 20 cm, sample and control volume 5 mL, pH not controlled)](image)
As result in the figure 4 shows, by increasing radiation exposure time, acetaminophen decomposition was increased. To optimization of other variable, time of 120 min was selected as a experimental time.

Study the effect of distance on the acetaminophen decomposition:

In order to study the effect of distance between light source and solution on the acetaminophen decomposition, various acetaminophen solutions with concentration of 0.001 M were prepared, and were exposed to radiation for 120 minutes with various distances. As results of absorbance differences show in the figure 5, distance of 10 cm has maximum decomposition. At the distance below 10 cm, radiation only from front part of the lamp bulb reaches to the solution. And at the distance greater than 10 cm, area of solid angle of light source was large and intensity of radiation was decreased.

![Fig. 5: Effect of distance on the acetaminophen decomposition (condition: Acetaminophen, 0.001 M, sample and control solution volume: 5 mL, power of compact fluorescent lamp: 40 W, exposure time: 120 min, pH: no control, λ = 254 nm)](image)

Effect of sample volume on the acetaminophen decomposition:

The effect of sample volume on the acetaminophen decomposition was studied with a 0.001 M acetaminophen solution with various volumes. Distance between sample and control solution and exposure time were selected 10 cm and 120 min respectively. As results in figure 6 shown, at the smaller volume, decomposition was increased, because the radiation passed the lower thickness of solution. Solution volume of 5 mL was selected as an optimum for the next experiments.

![Fig. 6: Effect of solution volume on the acetaminophen decomposition (condition: Acetaminophen, 0.001 M, power of compact fluorescent lamp: 40 W, exposure time: 120 min, distance: 10 cm, pH: no control, λ = 254 nm)](image)
Effect of acetaminophen concentration on the decomposition of acetaminophen:
The effect of the acetaminophen concentration on the decomposition of this compound with compact fluorescent lamp radiation was studied as follows: solutions of acetaminophen with various concentrations were prepared, and these solutions at the previous optimum conditions (5 mL volume, 10 cm distance and 120 minutes exposure time) were exposed to the radiation. In all experiments the solution contains acetaminophen with concentration same as sample solution, covered with aluminum foil was used as control solution. As results in figure 7 shown, by increasing acetaminophen concentration, decomposition was decreased, because the number density of acetaminophen molecules was increased and relative radiation energy that is reached to each molecule was decreased.

![Figure 7](image)

Fig. 7: Effect of concentration on the acetaminophen decomposition (condition: solution volume: 5 mL, power of compact fluorescent lamp: 40 W, exposure time: 120 min, distance: 10 cm, pH: no control, $\lambda = 254$ nm)

Study the effect of light source power on the acetaminophen decomposition:
In order to study the effect of light source, sample and control solution with 0.001 M concentration were exposed to various compact fluorescent lamp power radiations. Exposure time of 120 minutes, distance of 10 cm and volume of 5 mL were selected as optimum condition. Results of this experiment were shown in the figure 8. Based on this result, at the power greater than 40 W, amount of acetaminophen decomposition were maximum and constant.

![Figure 8](image)

Fig. 8: Effect of light source power on the acetaminophen decomposition (condition: acetaminophen concentration: 0.001 M, solution volume: 5 mL, exposure time: 120 min, distance: 10 cm, pH: no control, $\lambda = 254$ nm)
Effect of lamp angle on the acetaminophen decomposition:

In order to study the effect of light source angle on the acetaminophen decomposition, sample and control solution of 0.001 M acetaminophen were exposed to the 40 W compact fluorescent lamp at the 10 cm distance with various angles, according to figure 9.

![Fig. 9: Light source angles.](image)

As results of absorbance difference in the figure 10 shown, at the light source angle of 45°, amount of acetaminophen decomposition was maxima, because at the 45°, radiation from two sides and front of lamp bubble were reached to the solution, but in the other angle (e.g. 90°), only on sides of lamp radiates to the solution. Therefore the angle of 45° was selected as optimum angle for the next experiments.

![Fig. 10: Effect of light source angle on the acetaminophen decomposition](image)

Effect of temperature on the decomposition of acetaminophen with compact fluorescent lamp radiation:

In order to study the effect of time on the acetaminophen degradation with radiation of compact fluorescent lamp, sample and control solution of 0.001 M acetaminophen at various temperatures were exposed to the radiation. The distance between light source and solution was adjusted to 10 cm. Also other parameters, such as angle and exposure time were selected 45° and 120 minutes respectively. As results in figure 11 shown, by increasing temperature to 20°C, decomposition of acetaminophen was increased. At temperature between 20 to 50 °C, amount of decomposition was constant and independent of temperature, and at the temperature greater than 50 °C, elevating of temperature increase the decomposition of acetaminophen. The control chart in the figure 10 shows the only elevating of temperature does not affect significant on the acetaminophen decomposition. Therefore, there is the synergistic effect of temperature and radiation for composition of acetaminophen.
Study the synergistic effect of pH and radiation on the acetaminophen decomposition:

The synergistic effect of pH on the acetaminophen decomposition with compact fluorescent lamp radiation was studied as follows: solutions of 0.001 M acetaminophen with various pH were prepared with HCl and NaOH to pH adjustment, then these solutions with control solution were exposed to radiation of compact fluorescent lamp in the known condition, power of 40 W, source angle of 45°, temperature of 30 °C, exposure time of 120 minutes. Results of this experiment were shown in the figure 12. Based on these results, the synergistic effect of pH on the acetaminophen decomposition increased at the pH between 6 and 9. At the very acidic and very basic pH, the radiative decomposition of acetaminophen was suppressed with pH.
Conclusions:

The radiation of compact fluorescent lamp decomposed acetaminophen in the aqueous solution. The experimental parameters such as light source variables (distance, angle, power and time) and solution variables (acetaminophen concentration, solution volume, pH and temperature) affect the acetaminophen radiative decomposition significantly. The results of this study can be generalized to other organic compounds. Also the results can be used to environmental consideration to protect the human body from compact fluorescent lamp radiation.

ACKNOWLEDGEMENT

The source of data used in this paper was from MSc thesis and financial support was provided by Islamic Azad University, Firuzabad branch.

REFERENCES