



Investigate of Mercury Contents in Different Spent Fluorescent Lamps in Iran

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Abstract

The usage of fluorescent lamps is increasingly common in the world. The advantages of these lamps have led to consuming these kinds of lamps compared to incandescent lamps. But disposal of the fluorescent lamps because of containing heavy metals such as mercury is considered. The objective of this study is to confirm the comparison of mercury concentration in different linear and compact fluorescent lamps made in Iran. This study was conducted on two kinds of spent fluorescent lamps in Mashhad city in Iran. Lamp crusher (LAMP) was introduced as an eco-friendly method for obtaining the phosphor powder. Extracting mercury was done by acid leaching method. Mercury concentration was determined by cold vapor atomic absorption spectrometry. Mercury concentration in five kinds of spent fluorescent lamps T8, T10, CFL23W, CFL15W, and CFL11W was 372.52, 510.53, 55.65, 175.53 and 260.82 ppb, respectively. There are differences between Hg concentration and phosphor powder that might be due to some factors like the year of manufacture and the hours of operation. According to the Hg concentration from the powder and generation rate of the spent fluorescent lamps in the world and Iran, waste management of spent fluorescent lamps is necessary.

Keywords: Mercury, Phosphor Powder, Spent Fluorescent Lamps, Waste Management, Lamp Crusher Machine

1 Introduction

In recent years, spent fluorescent lamps (SFLs) have been widely used in Iran as a means of optimizing energy consumption (1). SFLs are a type of lamps with a glass tube coated with fluorescent materials (mainly as calcium hydrogen phosphate) that are filled with an inert gas (usually argon) and Hg (2, 3). It is estimated that, in the best condition, a normal fluorescent lamp contains about 30-40 mg of Hg that most of which is absorbed in the phosphor powders, aluminum, end caps and glass (4, 5).

The end-of-life fluorescent lamps typically last for over 6,000 hours, during which they have no threat to human health and the environment, while people may be exposed to toxic levels of the Hg vapor released from the broken lamps (6). Animals and humans exposed to broken compact fluorescent lamps as they absorb 80-97% of the inhaled Hg through lungs, leading to a potential risk of cross blood-brain-barrier between the placenta and the fetus (7, 8). The dangers of SFLs are quite serious due to their Hg content (9, 10). The amount of SFLs produced in Iran is a national problem and, if not managed in the future, may cause serious environmental and human

problems. About 620 million fluorescent lamps are discarded in the United States annually; many of them are broken during disposal. This amount distributes approximately 2-4 tons of Hg per year in the United States (11). The number of CFLs discarded in Iran in 2010, 2011, and 2012 was 159.802, 183.822, and 153.756 million per year, respectively. It is estimated that generation rates in 2013-2020 would probably vary from 163.621 million to 174.431 million annually. According to the population of Iran (75 million people), the waste generation rate of CFLs in this country was determined to be 2.05 per person in 2012 (12). In Mashhad city, the generation rate of spent compact and linear fluorescent lamps (CFLs and LFLs) was 6656 and 2180 thousand per year, respectively.

Currently, most researchers have focused on increasing recovery and recycling levels of these lamps for direct reuse and reducing the impact from Hg at end-of-life SFLs (7, 13-15). Among different methods proposed for their recovery and recycling, electrochemistry, chemical precipitation and extraction (16-19), microbial bioremediation (20, 21), and thermal desorption (17, 22) have been widely used as wet

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chemical analysis methods (17). Due to the massive cost of chemicals and the production of chemical waste substances, a limited number of studies have been conducted on introducing a high-performance, easy, inexpensive, and eco-friendly method for recycling and recovery of Hg from SFLs. Accordingly, the main objectives in the present study, a dry chemical analysis method is introduced to utilize minimize Hg emissions to the atmosphere, determining the concentration of Hg in phosphor powder different spent fluorescent lamps and waste management of spent fluorescent lamps in the world, Iran, and Mashhad city as the second metropolis of Iran.

2 Materials and methods

2.1 Materials

All chemicals used in this study were of analytical grade. Hydrochloric acid, nitric acid, Tin (II) chloride, and Pure Plus standard solution containing 1000 mg/l of Hg were obtained from Merck. All samples were filtered by the paper filter from

Whatman 42. Spent compact and linear fluorescent lamps were provided from Afratab and Pars Shahab brands. The specifications of these lamps are displayed in Table 1.

2.2 Instrumentation

2.2.1 Lamp crusher machine (LAMP)

This lamp crusher shown in Fig. 1. Removes Hg vapors, eliminates the dangers of this metal, and turns the lamp into small pieces. Cyclone filter, bag filter, carbon canister assembly (Includes activated carbon granules with 15% yellow sulfur and activated carbon filter), and HEPA filter are employed in a crusher to prevent the release of dust and vapors of Hg. More than 50% of phosphor powder inside the lamps is separated by cyclone filter. Fig. 2 illustrates the components separated from SFLs by the lamp crusher. The advantages of this apparatus include promoting the environment, ease of removal and installation in different places, facile operation, and no contamination in outlet air.

Table 1: Specifications of the lamps used for this work

Type of tube	Brand	Length (mm)	Diameter (mm)	Power (W)	Voltage (V)	Luminous flux (Lm)	Kind of lighting	Lamp life (h)	Base type
T8	Pars Shahab	1200	26	36	230	2375	Day Light	10000	G 13
T10	Pars Shahab	1200	32	40	230	2470	Day Light	10000	G 13
CFL 23W	Afratab	100	170	23	230	1400	Day Light	8000	E 27
CFL 15W	Afratab	70	130	15	230	750	Day Light	8000	E 27
CFL 11W	Afratab	70	140	11	230	600	Day Light	8000	E 27

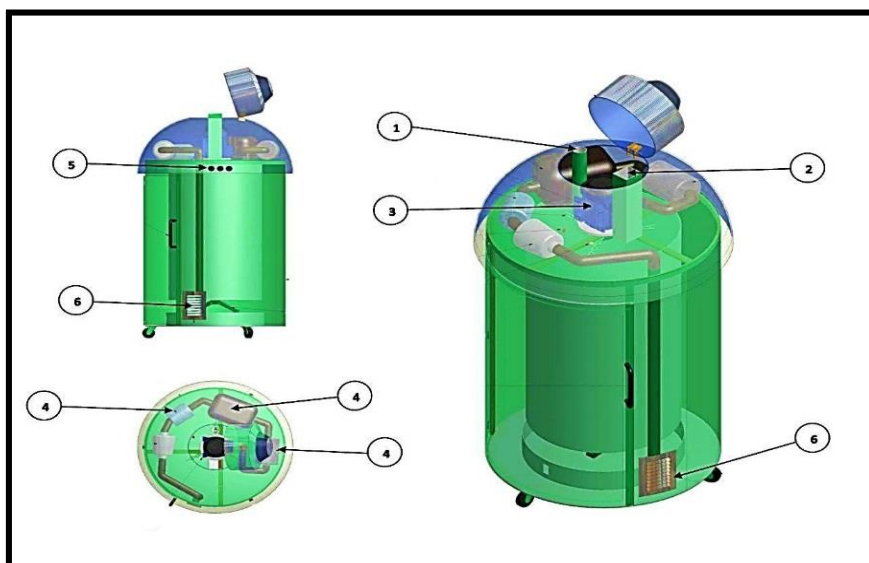


Figure 1: Schematic of the machine used for crushing the lamps: 1) Input linear lamp, 2) Input compact lamp, 3) Electromotor, 4) Input gas and phosphor powder, 5) Control part, and 6) Vapor Hg outlet



Figure 2: Output products of the lamp crusher: Separated aluminum (a), phosphor powder (b) and glass (c)

Table 2: Specification and main components of spent fluorescent lamps

specification	T8	T10	CFL 23W	CFL 15W	CFL 11W
component	Mass (g)	Mass (g)	Mass (g)	Mass (g)	Mass (g)
Phosphor powder	2.56	3.1	2.12	0.96	0.98
Separated glass	193.4	210.9	41.8	19.04	19.02
Separated phosphor powder	1.26	1.55	1.03	0.47	0.48
Base-cap	4	6	-	-	-
Total (Tube)	200	220	44	20	20

2.3 Sample preparation

This study was performed to determine the Hg combined in phosphor powder. In order to analyze the concentration of Hg by Atomic Absorption Spectrometry (AAS) with the manual cold vapor (Varian-AA240FS) and Vapor Generation Accessory (VGA), it is needed to use the Hg extraction method that permits it to be dissolved in a liquid solution. In this study, acid leaching was employed as an extraction method.

2.3.1 Extraction and measurement of Hg in the phosphor powder

Hg extraction was done for five kinds of SFLs. The ratio of mixed acid 4HCl:1HNO₃ (0.48 HCl mol/L: 0.15 HNO₃ mol/L) was used for Hg extraction. The phosphor powder from each lamp was weighed and poured into the volumetric flask; 4 ml from hydrochloric acid (37% v/v HCL) and 1 ml nitric acid (68% v/v HNO₃) were added. The solution was diluted using distilled water up to 100 ml in each volumetric flask. The samples were located on a shaker at the room temperature for 24 h and 3 RPM. Afterward, the solutions were filtered by the paper filter and then the samples were preserved in a refrigerator at -4°C until analyzed by CVAAS. For the analysis of Hg by VGA method, the standard solutions were prepared in 15, 30, 45, 60, and 80 µg/L. For the reducing agent, Tin (II) chloride (20% w/v SnCl₂) and for the oxidizing agent, deionized water was used.

2.4 Statistical analysis

The One-Way ANOVA test was conducted at 0.05 significance level to compare Hg concentration in different types of lamps by SPSS 16, the type of lamp had been assumed as a nominal measure and their concentration been as scale measure.

3 Result and Discussion

3.1 Specification and component of SFLs

Output products including the glass, the aluminum, and the phosphor powder are separated by the lamp crusher. The aluminum and the glass were recycled and the phosphor powder was converted to phosphoric acid and Hg sulfide was reused in industries. Specification and main components of SFLs are displayed in Table 2. CFLs have no aluminum, so in these lamps, the circuit is separated from the lamps at first and then sent to the machine. This lamp crusher is designed to reduce the volume of the lamps, which means that the lamps are crushed before being introduced into the factory by the primary recycling machine to prevent the environmental hazards of these wastes. By reducing the volume, service costs such as transportation decline to about 80%. The products obtained from this machine included vapor mercury, phosphor powder, and glass. Vapor mercury is captured by an activated carbon filter and HEPA filter. Finally, the air output of this machine is free of any contamination. Therefore, the HEPA filter provides clean air standard. The vapor mercury outlet

from this machine is <0.01 ppm, which is following environmental standards.

3.2 Hg concentration inside phosphor powder in different SFLs

The total amount of separated phosphor powder by crushing machine was used for each lamp. It shows the amount of Hg in each lamp in the ratio of 4HCl:1HNO₃. Mercury concentration in phosphor powder in each lamp are displayed in Table 3. Our analysis demonstrated that these data were significant at the 0.05 level.

Table 3: Mercury concentration in phosphor powder of CFLs and LFLs

Types of lamps	Hg concentration (ppb)
T8	375.52±6.7
T10	510.53±0.5
CFL 23W	55.65±6.7
CFL 15W	175.53±6.6
CFL 11W	260.82±0.02

The literature review showed about 80% of Hg exists in phosphor powder (8, 17, 23, 24). For this reason, Hg in phosphor powder is an important source of public health concern when these lamps are broken (17). Also, the results of the Korea Extraction Method (KET) and Toxicity Characteristic Leaching Procedure (TCLP) tests showed that phosphor powder should be managed as a hazardous waste but base-cap and glass are not classified as hazardous waste (24). Our results demonstrated, the separated phosphor powder in LFLs T10, and T8 was 1.55 g and 1.26 g, respectively. The mercury concentration in T10 was 510.53 ppb while in T8 it was 375.52 ppb. So, it can be stated that the more available the phosphor powder, the higher the amount of mercury would be. In other words, there is more mercury in fluorescent lamps in the phosphor powder because the mercury is involved in the process of lighting (24). Comparison of mercury distribution in LFLs between our results and study by S.-W. Rhee et al. 2014 are displayed in Table 4. On the contrary, in the CFL 11W, the amount of phosphor powder was lower, but the mercury concentration was high compared to the other CFLs. Such a difference can be explained by the previous studies that during the use of lamps elemental mercury from the vapor phase diffuses onto aluminum end caps or glass matrices but phosphor powder prevents the mercury from being absorbed into the glass (8, 17). The results of this study about the Hg concentration in phosphor powder in CFLs similar to the study by Rey-Raap and Gallardo 2012. The point is that we do not have information about the life of the lamps used, so differences between the lamps might be due to factors like the year of manufacture, the hours of operation, type of the lamps and the processes of the separation by the recyclers (11, 17, 23-26).

Table 4: Comparison between the amounts of mercury in phosphor powder in LFLs

Specification component	Spent T8 (this work)	Spent T10 (this work)	LFL-A(24)	LFL-B(24)	LFL-C(24)
Separated Phosphor powder	375.52 (ppb)	510.53 (ppb)	1348.223 (ppm)	1746.353 (ppm)	1525.742 (ppm)

4 Conclusions

The present study was conducted to introduce a lamp crusher machine (LAMP) as one of the methods for reducing the volume of the lamps for primary recycling. The machine separated phosphor powder from these lamps, which contained 80% Hg. Acid leaching was applied for extracting Hg from the powder. Five kinds of SFLs were used for extracting Hg by the ratio of 4HCl:1HNO₃. According to the Hg concentration from the powder and generation rate of the SFLs in the world and Iran, waste management of this kind of lamps is necessary.

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Competing interests

The authors declare that they have no competing interests.

Authors' contributions

All authors participated in the data collection, analysis and interpretation. All authors critically reviewed, refined and approved the manuscript.

Ethical issue

The authors have comprehensively observed ethical issues including plagiarism, misbehavior, data fabrication and no data from the study has been or will be published separately.

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