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# Determining heavy metals in spent compact fluorescent lamps (CFLs) and their waste management challenges: Some strategies for improving current conditions

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ABSTRACT

From environmental viewpoint, the most important advantage of compact fluorescent lamps (CFLs) is reduction of green house gas emissions. But their significant disadvantage is disposal of spent lamps because of containing a few milligrams of toxic metals, especially mercury and lead. For a successful implementation of any waste management plan, availability of sufficient and accurate information on quantities and compositions of the generated waste and current management conditions is a fundamental prerequisite. In this study, CFLs were selected among 20 different brands in Iran. Content of heavy metals including mercury, lead, nickel, arsenic and chromium was determined by inductive coupled plasma (ICP). Two cities, Tehran and Tabriz, were selected for assessing the current waste management condition of CFLs. The study found that waste generation amount of CFLs in the country was about 159.80, 183.82 and 153.75 million per year in 2010, 2011 and 2012, respectively. Waste generation rate of CFLs in Iran was determined to be 2.05 per person in 2012. The average amount of mercury, lead, nickel, arsenic and chromium was 0.417, 2.33, 0.064, 0.056 and 0.012 mg per lamp, respectively. Currently, waste of CFLs is disposed by municipal waste stream in waste landfills. For improving the current conditions, we propose by considering the successful experience of extended producer responsibility (EPR) in other electronic waste management. The EPR program with advanced recycling fee (ARF) is implemented for collecting and then recycling CFLs. For encouraging consumers to take the spent CFLs back at the end of the products' useful life, a proportion of ARF (for example, 50%) can be refunded. On the other hand, the government and Environmental Protection Agency should support and encourage recycling companies of CFLs both technically and financially in the first place.



## 1. Introduction

Although compact fluorescent lamps (CFLs) have been available for more than three decades, in Iran they have become a popular lighting choice instead of incandescent lamps only during the recent years, which was due to payment of governmental subsidies, efforts of Ministry of Power, lower energy consumption of CFLs (approximately 75% less energy compared with incandescent lamps) and their longer life and lower retail price (Travis, 2011; Nance et al., 2011; Shao et al., 2012). It is estimated that, in the coming years, as a result of eliminating energy subsidies by the government, increasing electricity price, implementing new policies of energy consumption reduction and encouraging and educating people for using CFLs, applying CFLs will rapidly increase in Iran (Nance et al., 2011; Travis, 2011; Sadeghzadeh, 2012). From environmental viewpoint, the most important advantages of CFLs over incandescent lamps are reduction of green house gas emissions (especially $CO_2$), decreasing calamite change rate and also decreasing mercury entry into the environment due to great reduction in energy use (A power plant will emit 10 mg of mercury to produce the electricity to run an incandescent bulb compared to only 2.4 mg of mercury to run a CFL for the same time). On the other hand, the main disadvantage of CFLs is the waste disposal of spent lamps because of containing a few milligrams of toxic components, especially mercury and lead (Dos Santos et al., 2010; Nance et al., 2011; Travis, 2011; USEPA, 2014). Using mercury (elemental and inorganic forms) in fluorescent lamps is

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essential for their proper working and a suitable replacement has not been found yet (Éder José Dos Santos et al., 2010; Nance et al., 2011). The amount of mercury content in spent CFLs has been reported from 0.1 to 50 mg/lamp. The CFLs that have been produced recently contain on average 1.5–3.5 mg/lamp mercury (Shao et al., 2012; Travis, 2011; Li and Jin, 2011; Newmoa (Northeast Waste Management Officials Association), 2008; Boughey and Webb, 2008; Rey-Raap and Gallardo, 2012; Culver, 2008). Values of lead content of each lamp were reported between 0.07 and 0.75 mg (Dos Santos et al., 2010). Mercury content of each compact fluorescent lamp, according to European Community Regulation, should not exceed 5 mg/lamp. By disposing spent CFLs in municipal solid waste management system and breaking them during handling, placement/storage, hauling and final disposal, its content toxic element such as mercury and lead is released into the environment (Travis, 2011; Dos Santos et al., 2010). Mercury is one of the most toxic elements on the earth and its release into the environment, its introduction to the biochemical cycle and finally its entrance to the food chain are among the great concerns worldwide (Raposo and Roeser, 2001; Rey-Raap and Gallardo, 2012). Moreover, global warming and climatic changes are expected to accelerate mercury remobilization and bioaccumulation in the environment and ecosystem with subsequent risk increase of human exposure (Raposo and Roeser, 2001). Mercury can accumulate in brain and kidneys and cause changes in neurological and renal functions. Central nervous system is known to be the most sensitive target for exposure to mercury. Exposure to mercury has caused neurological and behavioral disorders in humans (Nance et al., 2011). Lead is among the most important environmental pollutants. Among the potential of heavy metals for human health and safety which is highlighted by their ranking, first arsenic (As), second Pb and third Hg are on the priority list of substances found in hazardous waste sites (ATSDR, 2007). Other heavy metals like nickel and chromium are important from environmental and health viewpoints.

Waste of spent CFLs is one of the fastest-growing waste streams in Iran, as it is in the other countries. Nevertheless, waste management of spent CFLs has not received sufficient attention. Therefore, planning a waste management program for spent CFLs is necessary to prevent the above-mentioned effects on human health and the environment. For successful implementation of any waste management plan, availability of sufficient and accurate information on quantities and characteristics of the generated waste and the current management conditions is one of the fundamental prerequisites (Taghipour et al., 2012).

Currently, in Iran, there is no available and accurate information describing actual practice of management and handling of waste of spent CFLs. Also, the data available to date on characteristics of CFLs, especially from heavy metal content viewpoint and waste production rates, are rare in Iran. Determining the amount of heavy metals content including mercury, lead, nickel, arsenic and chromium in CFLs was one of the key objectives of the present work. Another objective of this study was to assess waste handling of CFLs and their final disposal. This study also aimed to assess the existing policies on waste management of spent CFLs; in addition, it had some practical recommendations about waste management of CFLs in Iran, in order to improve the current situation.

## 2. Methodology

### 2.1. Sample preparation

In this study, the spent CFLs from 20 different brands (domestic and international) being sold in Iran's market, were collected from various household or office consumers in the year of 2013 (of which most being produced after 2008, and some before that). Then, contents of heavy metals (mercury, lead, nickel, arsenic and chromium) were determined by inductively coupled plasma-optical emission spectrophotometer (ICP-OES). Following the methodology described by Jang et al. (2005), in this study in order to determine the studied heavy metals, each lamp was being wiped clean with deionized water. After cleaning, each lamp was placed on a 140 $\times$ 25 cm laboratory bench paper. Then, the lamp was separated into two parts (end caps and glass) by pliers and each part was weighed. Afterward, the inside of each lamp was washed with about 50 mL of deionized water for 30 min (for separation phosphor powder (fluorescent) from glass). The solution was then collected in a 100-mL volumetric flask. The mixed acid solution of hydrochloric acid and nitric acid was added to this solution to be 5% (v/v) for each acid solution. Next, total volume was adjusted to 100 mL with additional deionized water. The solution was stirred at room temperature for 24 h before the analysis by inductively coupled plasma-optical emission spectrophotometer. The lamp glasses were dried under vacuum at room temperature for 4 h and wrapped in laboratory bench paper and then shattered into 2–3 in. pieces by a hammer. The glass was gently pulverized by a grinder into small particles in order to obtain more homogeneous samples for the analyses. The pulverized particles were collected in a pre-cleaned 300-mL capped vessel. Before the analysis, the samples were preserved in a refrigerator at 4 C. For analyzing, 25 g of the pulverized glass from each lamp was added to a pre-cleaned 100-mL capped-vessel and digested by a mixture of 12.5 mL reagent water, 12.5 mL aqua regia and 6.5 mL potassium permanganate solution, which could be designated as the digestion mixture. Aqua regia was prepared immediately before use by carefully adding three volumes of concentrated HCl to one volume of concentrated $HNO_3$. Potassium permanganate was prepared at 5% according to weight to volume basis. The capped vessel was mixed using a shaker for 18 ± 2 h at room temperature. The supernatant was then filtered by a 0.45-μm pore size filter and diluted by mixed acid solution of hydrochloric acid (5%, v/v) and nitric acid (5%, v/v) to stay within the range of the standard curve. The prepared laboratory samples for metal testing including Hg, Pb, Ni, As and Cr were subjected to ICP-OES (German SPECTRO Company, Spectro Atcos Model) instrument to quantify composition of the given samples. The detection limit for mercury, lead, nickel, arsenic and chromium were 0.1, 0.1, 0.5, 0.1 and 0.2 μg/L respectively

### 2.2. Estimating waste of CFLs and current condition of waste management

Waste resulting from obsolescence of CFLs was estimated by considering both domestic production and imports minus the export of those lamps during 2007–2012. The CFLs that were probably illegally imported were not included in the study, owing to the data uncertainty. The methodology used in this study for estimating generation rate of spent CFLs was based on the data collected from National Statistics Organization, Ministry of Industry and Mining. The amount of annual CFLs (number/year) was estimated based on average mass of each CFL and average lifespan assumptions (2.5 years for each lamp according to average lifespan announced by lamp producers). A multilayer perception artificial neural network using batch training method and gradient descent algorithm was used to predict production of spent CFLs. The analyses were performed utilizing SPSS 17 statistical software. Multilayer perception (MLP) procedure is an artificial neural network that produces a predictive model for one or more dependent (target) variables based on values of the predictor. It consists of a network of neurons which map predictor to dependent variables. In this procedure, each artificial neuron consists of a linear combination of weighted predictors, passing though a non-linear activation function and hidden layers to produce the neuron's output.