Potential mercury emission from fluorescent lamps production and obsolescence in mainland of China

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Abstract

Fluorescent lamp (FL) has experienced a rapid expanding on its usage due to its energy-saving feature of energy-saving in recent years, and it is widely used all over the world. However, the potential mercury emission during production and after breakage while it is in use or discarded are drawing increasing concerns from the public as a consequence. This article focuses on evaluating the potential mercury used for FL production and the potential emission during its production and breakage in mainland of China. It is evaluated that about 21.20 metric tons of mercury was used for the FLs production in 2013, where 19.98

metric tons remained and 1.22 metric tons could be released into the environment. 19.95 metric tons of mercury could be released from waste FLs after discarded. In 2020, the mercury consumption is estimated to be reduced to 13.51 metric tons through the improvement on mercury dosing technology and the strengthener of limitation on mercury content in FLs, getting in this way that the amount of mercury remain in FLs and released during production could be 12.79 and 0.72 metric tons, respectively; the mercury released from waste FLs could be about 6.48 metric tons.

Keywords

Fluorescent lamps, mercury, estimation, consumption, emission, distribution

1. Introduction

Electricity consumption by lighting is an important part of the society electricity demand. For example, it accounts for about 12% and 10% of the total electricity consumption in China and Germany, respectively (Frondel and Lohmann, 2011; NDRC et al., 2011). Fluorescent lamp (FL) has the feature of obvious energy-saving and long lifespan when compared with traditional incandescent lamps. More than 65% of the energy consumed in using stage can be saved when replacing incandescent lamps with FLs, and the lifespan of FLs is also more than 10 times than the incandescent lamps (U.S. DOE, 2013). Many countries, including Canada, the U.S., as well as the European Union countries (Waide, 2010), have been working on eliminating incandescent lamps by forbidding their import and sale since Australia began phasing them out in 2007 (AU. DOI), 2009).

China also announced a national plan on November 1st 2011, and started the prohibition process on October 1st 2012 (NDRC et al., 2011). Beside this, China has been become the largest FLs production base in the world. In 2011, China produced 7.024 billion FLs units, which is more than 28 times of the production in 1994 (CNIS, 2002; Ye et al., 2012). An accelerated obsolescence of FLs and flow into the solid waste stream can be expected during the next years in China, due to the gradual elimination of ILs and expanding usage of FLs. Based on the authors' previous study, it is estimated that the FLs production in mainland of China would reach up to about 9.40 billion units, and the amount of waste FLs in the same year would be about 4.13 billion units; the production and waste FLs generation in 2020 would be 11.90 and 5.84 billion units, respectively (Tan and Li, 2014).

However, mercury, a heavy metal with a high toxicity, is an indispensable component for a FL. It converts the electron flow into ultraviolet radiation, then the fluorescent phosphors coating inside the glass envelope of the lamp is excited to generating visible light by ultraviolet radiation (European Commission, 2013). A FL contains milligrams of mercury to make it works properly. According to the study conducted by Shao et al. (2012) in the largest FLs production province, Zhejiang, China, the soils and vegetables from the sites near CFL manufacturing plants showed higher Hg concentrations than samples from control sites, and the surrounding environment was actually affected by the production process. In addition, when FL is broken intentionally or accidentally, mercury releases into the atmosphere and biosphere, which represents a risk to human health. It was demonstrated in the study by Nance et al. (2012) that the risk of mercury emission from CFL breakage in a room could exceed the relevant risk targets under certain scenarios. Sarigiannis et al (2012) also pointed out that the indoor air concentration of mercury vapor may exceed the Reference Exposure Limit (REL) for mercury vapor set by the Environmental Protection Agency of California.

The FLs industry was one of the major mercury consumption fields in China (CCICED, 2011). In recent years, increasingly public concerns have been drawn to the potential risk of mercury exposure caused by FLs production, waste FLs breakage and disposal. In response, Chinese government issued a national plan on reducing the mercury content in fluorescent lamps, on 18th February, 2013 (MIIT et al., 2013), aiming to eliminate the obsolescent liquid mercury dosing technology by replacing it with amalgam technology for FLs production, as well as making preparation for the upcoming Minamata Convention on Mercury.

Despite these above, the need to manage the FLs production and waste FLs in an environmentally sound path has been becoming increasingly urgent in China. Especially, because there is no collection or disposal system established for the waste FLs stream, and most of the waste FLs are entering to the municipal solid waste treatment facilities, which make difficult for recovering rare earth from phosphors in waste fluorescent lamps (Tan et al., 2014). Based on the previous study on prediction of FLs future production and waste FLs generation and distribution in mainland of China, this article focuses on evaluating the potential amount of mercury used for FLs production and the potential emission during their production and breakage in mainland of China. It is expected to provide a comprehensive understand of the mercury risk from FLs in mainland of China by quantified estimation.

2. Materials and methods

The production of FLs, generation and distribution of waste FLs in mainland of China had been predicted in previous study by the authors (Tan and Li, 2014). The extended logistic model was used for the FLs production prediction from 2012 to 2020 based on the historical data of FLs production from 1995 to 2011. The modified Market Supply Method was selected for waste FLs generation, and the volume of waste FLs from 2011 to 2020 was evaluated. Regional distribution of waste FLs was evaluated combined with the regional lighting demand. Detailed annual FLs production, waste FLs generation and distribution can be found in the previous study by the authors.

As for the potential mercury consumption for the FLs production, the limits on content of mercury in various FLs were summarized. The proportion of FLs applying the solid amalgam and liquid mercury technology for mercury dosing during the production was investigated. Furthermore, the amount of mercury that would be lost during the production, which was related to the dosing technology, was investigated as well. Studies focusing on the mercury emission from waste FLs were reviewed for determining the content of mercury that could be released after waste FLs breakage.

3. Results and discussion

3.1. Trends of mercury content in FLs

A good deal of mercury content reduction had obtained since the 1990s according to a report for Natural Resources Defense Council (NRDC) of U.S. Before the early 1990s, the mercury content in T12 fluorescent lamp was slightly over 40 mg. It reduced to about 30 mg and then slightly over 20 mg in 1990s, and went a step further to about 10 mg in 2000s. For the T8 fluorescent lamp, the mercury content was about 30 mg in early 1990s, it reduced to about a half in late 1990s and then 8 mg in early 2000s; for the CFLs, the mercury content was less than in the linear FLs, less than 8 mg in early 2000s (Dunmire et al., 2003). In 2010, it was reported that the mercury content in linear fluorescent lamp in Chinese market was 5~10 mg generally, and a few enterprises could reach 3~4 mg or even better; it was 3~5 mg for compact fluorescent lamp with some products contained less than 3 mg even 1 mg (Li et al., 2013).

Requirements for content limits of mercury in fluorescent lamp was set to 5 mg and 10 mg for compact and linear ones by Chinese government in 2006. A stricter requirement was announced in July 2012 and enacted in October of the same year, the limitation of mercury content in fluorescent lamp was set to 3 mg and 5 mg for compact and linear ones. Furthermore, a detailed roadmap for gradually reducing the mercury content in FLs was announced in February 2013, facing to the challenges of the increasingly stringent restriction for mercury usage in FLs from the recast European RoHS Directive and soon coming Minamata Convention on Mercury. The progress of requirements for content limits of mercury in FLs was illustrated in the figure 1.

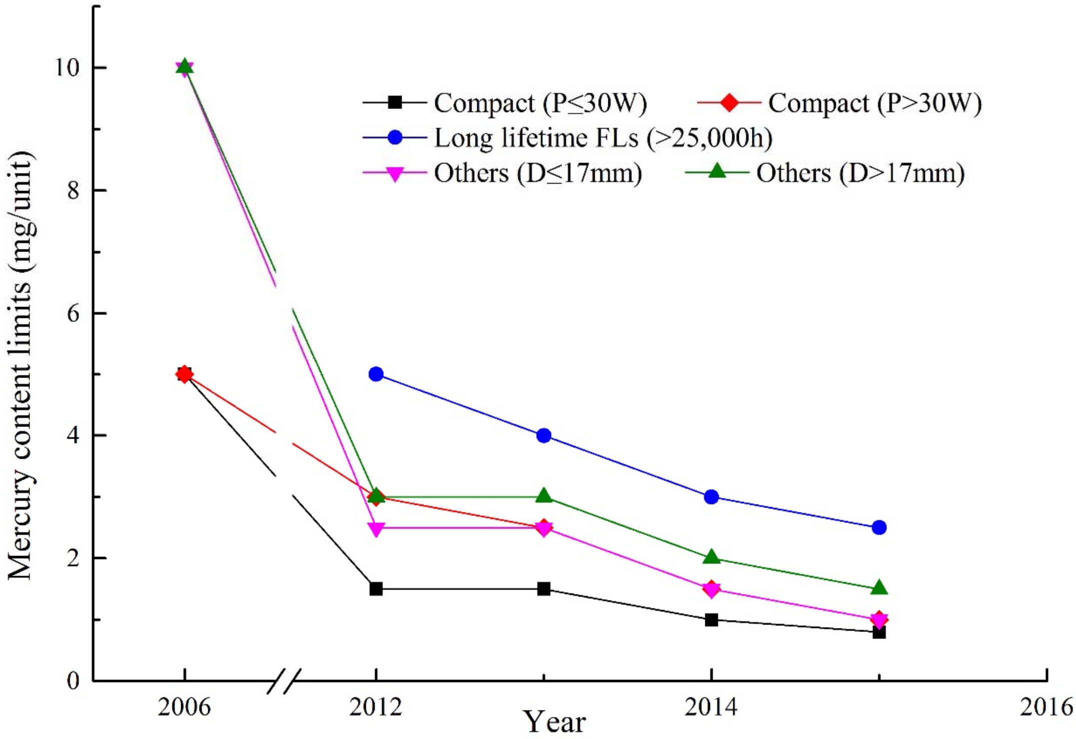

Figure 1 Content limits for mercury in fluorescent lamps

Note: “P” means the power wattage of FLs; “D” means the diameter of other types of FLs except for the compact and long lifetime FLs.

3.2. FLs production technology progress and mercury liberation potential

At the present, two different forms of mercury are being used for FLs production in China, including the solid amalgam form and liquid form. The solid amalgam mercury dosing technology causes less mercury release than the liquid mercury technology during the production (Megaman, 2010). It was presented that about 5.26% mercury would be lost during the solid amalgam mercury dosing process, while the average mercury loss percentage was 9.09% for the liquid mercury technology (Li et al., 2013). The proportion of FLs products using the solid amalgam mercury had been increasing continuously in recent years, it was about 77%, 83% and 95% for compact, linear and circular FLs in 2010, respectively (Li et al., 2013).

Studies had been carried out by researchers for concerning the potential exposure risk from FLs breakage. It was demonstrated that mercury in FLs would diffuse through the fluorescent phosphors during the lifetime. Although some differences existed between different studies for the mercury distribution, more than 80% of the mercury in FLs is contained in the fluorescent phosphors, and the glass has over 10% of the mercury amount in FLs (Jang et al., 2005; Rey-Raap and Gallardo, 2012; Rhee et al., 2013), which makes the mercury emission from broken FLs would last for weeks or even months. The most proportion of mercury liberated to the atmosphere was 75% during experiments (Aucott et al., 2003; Li and Jin, 2011). It was estimated that more than 95% of the mercury amount in FLs could be released if no measures are taken to control the emission (Li and Jin, 2011, Aucott et al., 2003).

3.3. Potential mercury consumption and emission evaluation

An evaluation on mercury consumed during FLs production and potential emission from waste FLs breakage was made using the prediction results gotten from the authors' previous study (Tan and Li, 2014). When considering the pressure from strengthening strict limitation on mercury content in FLs, the assumed value for proportion of FLs using solid amalgam mercury technology was set as 80%, 85% and 95% for compact, linear and circular FLs in 2012; moreover, it was assumed that the annually growth ratio of proportion would be 5%, 5% and 1%, respectively, with the maximum value of 99%. The worst scenario for mercury emission from waste FL after its breakage was set for the evaluation. It was assumed that all the mercury in waste FL would release into the environment eventually. Evaluated mercury consumption of FLs industry and potential mercury emission from domestic waste FLs after breakage was illustrated in figure 2.

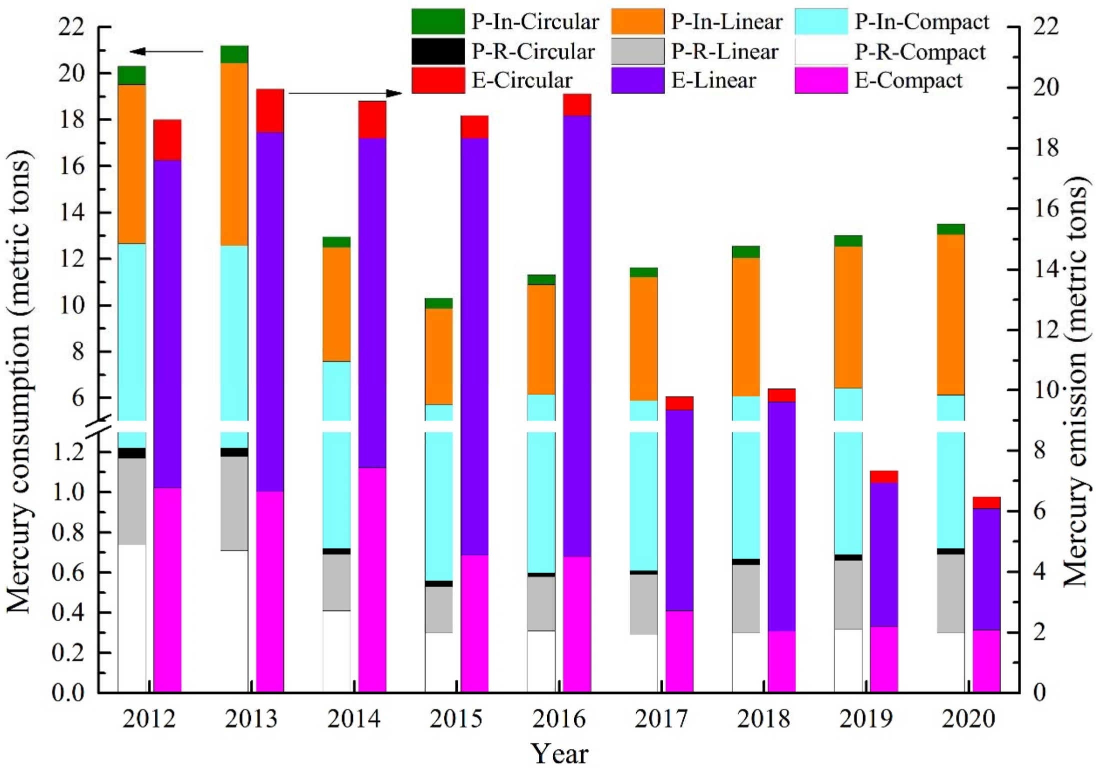

Figure 2 Mercury consumption during FLs production and potential emission from domestic waste FLs

Note: "P-In" mean mercury remain in the FLs during production; "P-R" mean mercury lost or released during production; "E" mean the potential emission after breakage.

It could be concluded that the mercury consumption by FLs industry and potential emission from waste FLs would be reduced obviously with good implementation of the policy and/or regulation on FLs mercury content reduction. In 2015, the last year of the reduction roadmap for mercury in FLs, it was evaluated that the amount of mercury consumption by FLs industry could be reduced to 10.30 metric tons, of which 9.75 metric tons would remain in the FLs while about 0.55 metric tons would release into the environment. The evaluated amount of mercury consumption in 2015 would be about 13.34% as it in 2007. The potential mercury emission from waste FLs in 2015 was about 19.07 metric tons, which was approximately the same amount of atmospheric mercury emission from solid waste in 2007 (CCICED, 2011); while, it would reduce to about 9.79 metric tons in 2017, about 51.94% as it in 2015, because the limits on content of mercury in FLs enacted in 2012.

Subsequently, the mercury consumption would gradually increase with the growth of FLs production and domestic use. In 2020, the evaluated amount of mercury consumption for FLs production could reach 13.50 metric tons, of which the amount of mercury remained in FLs and released during production would be about 12.79 and 0.72 metric tons, respectively. The amount consumed would be about 17.53% as it in 2007. The potential emission could reach 6.48 metric tons and would be about 33.59% of the atmospheric mercury emission from solid waste in 2007 (CCICED, 2011).

It was presented that the surrounding environment of FLs factories were actually affected by the mercury released during the FLs production process. Higher mercury concentration were presented in the soil and food from FLs production sites than control sites (Shao et al., 2012). Decreasing the mercury emission during FL production by promoting the technology substitution and mercury content requirements could show promising environment benefits. Compared with the amount of mercury lost during FLs mercury production in 2010, the amount could be decreased to about 0.55 metric tons in 2015 with a reduction of 75% approximately; in 2020, it would be about 1/3 of it was in 2010. As shown in figure 3 was the distribution and trend of mercury loss during FLs production in China, the Zhejiang province, where was the largest production of FLs in China (Shao et al., 2012), had the most mercury amount released during FLs production followed by the Guangdong, Jiangsu, and Fujian province. In 2010, the mercury released in Zhejiang province was about 0.81 metric tons, and it could be reduced to about 0.21 and 0.27 metric tons in 2015 and 2020, respectively.

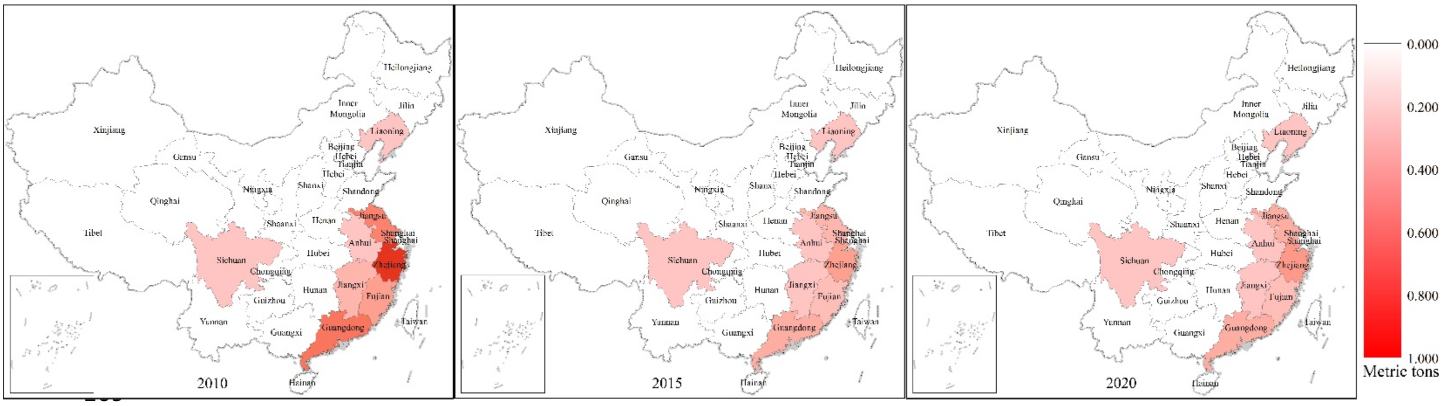

Figure 3 Distribution and trends of mercury loss during FLs production

However, as for the distribution of potential mercury emission in mainland of China, the Guangdong province had the most mercury emission potentially followed by the Jiangsu, Shandong, and Zhejiang province. The estimated amount of potential mercury emission in Guangdong would be about 1,710 kilograms in 2015, then reduce to about 560 kilograms.

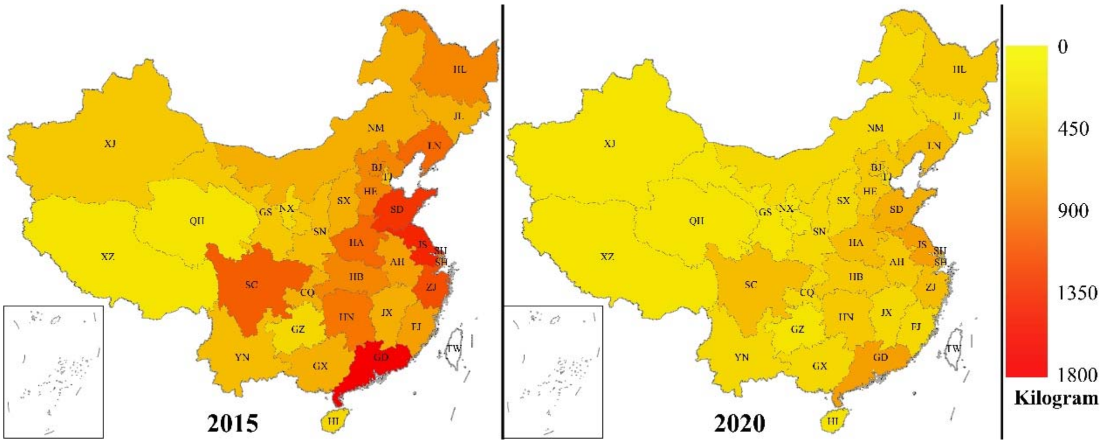

Figure 4 Distribution and trends of mercury emission from waste FLs

Note: The area filled with white color does not need to be considered here.

Presently, the thermal desorption process for the decontamination and recovery of mercury in FLs is well widely used (Chang et al., 2009; Durão Jr et al., 2008; Jang et al., 2005). Mercury containing residues generated in waste FLs disposal process were distilled under 500 centigrade degree for 5h, the mercury content was reduced to below 1 mg/kg (Jang et al., 2005). In an aggressive scenario, if a take-back system are well established and operated with most of the waste FLs collected and mercury recovered, the amount of mercury released from waste FLs could be reduced to less than 0.94 metric tons. Therefore, establishing collection system and taking back waste FLs, as well as recovering the mercury, should improve the prevention and control of mercury pollution form waste FLs significantly, promote the recycling of waste glass, rare earth elements and other metallic components, also contribute to environmentally sound management of waste FLs.

4. Conclusion

Fluorescent lamps (FLs) are widely used because of the feature of energy-saving and long-life compared with traditional incandescent lamps. In addition, the usage is expected to expand. However, for the potential health risk caused by mercury exposure, FLs production and the management of waste FLs have attracted the attention and concerns from the public increasingly. To have a realistic understanding of the mercury issue from FLs and to contribute to establish a management system for waste FLs, we evaluated the amount of mercury consumption and release during FLs production and emission from waste FLs in following years.

It is evaluated that about 21.20 metric tons of mercury would be consumed for FLs production in 2013, of which 19.98 metric tons would remain in the FLs while about 1.22 metric tons would release into the environment. Zhejiang is the province that of the most mercury release during FLs production, and the Guangdong province has the most amount of potential mercury emission from waste FLs. 19.95 metric tons of mercury could be released from waste FLs after discarded. The amount of mercury consumption by FLs production and emission from waste FLs could be reduced by the reduction requirements on mercury content in FLs and technology upgrading; otherwise, it would rise with the growth of FLs production and usage when no further requirements exist. The consumption of mercury is evaluated to be about 10.30, 11.63 and 13.50 metric tons in 2015, 2017 and 2020, while the emission from waste FLs would be about 19.07, 9.79 and 6.48 metric tons, respectively.

Establishing collection and taking back waste FLs systems, and recovering the contained mercury can contribute for prevention and control of relevant mercury pollution significantly. The amount of mercury emission is estimated that can decrease to below 0.94 metric tons with collection and recovery systems well operated for most of the waste FLs.

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