Submission from the EU on mercury-added products and manufacturing processes using mercury or mercury compounds

In accordance with Decision MC-3/16: *Review of Annexes A and B*, the Secretariat called in a letter dated 13 December (MC/COP3/2019/15) for submissions from Parties by 31 March 2020, including:

a) Information on mercury-added products and on the availability, technical and economic feasibility, and environmental and health risks and benefits of non-mercury alternatives to mercury-added products, pursuant to paragraph 4 of article 4 of the Convention

b) Information on processes that use mercury or mercury compounds and on the availability, technical and economic feasibility and environmental and health risks and benefits of mercury-free alternatives to manufacturing processes in which mercury or mercury compounds are used, pursuant to paragraph 4 of article 5 of the Convention

The EU would like to share the information on a number of products and processes listed in table 1 below, where EU law is stricter than the provisions of the Convention. Each product/process is covered in an individual fiche, including data sources and references. The submission also includes a fiche on re-emerging use of mercury used as propellant in ion engines. New information has surfaced regarding this specific use which is likely to cause a significant dispersion of mercury to the environment.

Note that the EU submission is based on the European Commission study on the "**Collection of information on mercury-added products and their alternatives**". The final report has a wider scope than the EU submission as it also covers a number of other existing or emerging uses and has been published and made available on **CIRCABC**. It provides information regarding (1) existing mercury uses prohibited or restricted under EU law but not under the Convention, and (2) emerging uses of mercury and mercury compounds in products and processes.

Table 1 Products and processes included in EU submission

Products
Batteries (Mercury-containing button cells)
Compact fluorescent lamps (CFLs)
Linear fluorescent lamps (LFLs)
High Pressure Sodium Lamps (HPS)
Other Fluorescent Lamps
Non-fluorescent Low Pressure Discharge Lamps
Eye Make-up Products
Melt Pressure Transducers
Strain Gauges
Mercury Vacuum Pump
Tensiometers
Processes
Production of VCM
Production of polyurethane
All other production processes using mercury as an electrode
All other processes using mercury compounds as a catalyst
Emerging uses
Use of mercury as propellant in ion engines (satellite fuel)

Batteries (mercury-containing button cells)

Summary Overview

Button cells are small, thin energy cells commonly used in watches, hearing aids, and other electronic devices. Mercury-containing button cell batteries mainly fall into three types: zinc air, silver oxide and alkaline.

Currently, the Minamata Convention provides an exemption to button zinc silver oxide and button zinc air batteries with a mercury content below 2%. This exemption was also active in the EU under Directive 2006/66/EC (Batteries Directive) until 2015, however since then,the placing of batteries containing more than 0.0005% of mercury on the market has been prohibited. In the USA, mercuric oxide button cell batteries have been banned since 1996.

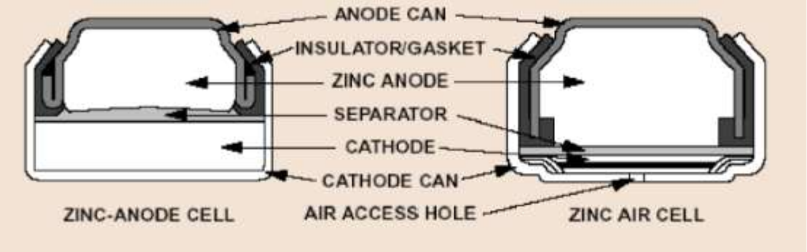
Mercury-free button cells are available, the most common being zinc air batteries, and are technically feasible for all applications. They cost approximately 10% more than mercury cells (BIO Intelligence, 2012). Mercury-free zinc air batteries mostly have similar performance regarding self-discharge, leak resistance and capacity (BIO Intelligence, 2012), but a reduction of their lifespan,by 2-10% can be observed. However, improvements in performance are expected (European Commission, 2014). There are also economic benefits to waste collectors and recyclers from mercury-free alternatives in the form of a 30-40% lower cost of recycling button cell waste (BIO Intelligence, 2012).

According to Lin et al. (2016), the production of mercury-containing zinc button cell batteries in China has gradually decreased from 8.8 billion units in 2005 to 5.5 billion units in 2014. In the EU, in 2010, the EU button cell market was 1.08 billion units containing an estimated 1.4 to 8.8 t Hg and displaying an upward trend (BIO Intelligence, 2012).

Technical Description

Currently, there are three types of button cell batteries that contain mercury: zinc air, silver oxide and alkaline. These batteries contain mercury in small amounts (typically 0.1-2%) (European Commission, 2014) and the purpose of mercury in the cell is to prevent the build-up of hydrogen gas. The mercury acts as a barrier to the production of hydrogen and as such prevents the cell swelling and becoming damaged.

Figure 1 – Cross Section of Zinc Anode Button Cell and Zinc Air Button Cell (European Commission, 2014)



Range of mercury content/consumption per unit product

0.1-2 weight-% (button cells with intentionally added mercury)

0.0005 weight-% (button cells without intentionally added mercury)

Availability of non-mercury alternatives

Main alternatives: Mercury-free zinc air batteries

Mercury-free versions are commercially available for all applications of the main types of button cells (lithium, silver oxide, alkaline and zinc air). The most frequently used types make use of zinc air technology (European Commission, 2014).

Since October 2015, mercury-containing button cell batteries have been prohibited in the EU following the expiry of the exemption granted under the Batteries Directive.

Technical feasibility of mercury-free alternatives

In the USA following a ban of mercury-containing button cells, there were initial issues relating to performance and usability of mercury-free alternatives however, these have now been overcome following technological developments.

Stakeholders have confirmed that performance parameters such as self-discharge, leak resistance, capacity and pulse capability of mercury-free button cells are comparable to traditional mercury-containing cells (BIO Intelligence, 2012).

Economic feasibility of non-mercury alternatives

Mercury-free alternatives currently cost approximately 10% more than mercury-containing cells to consumers (BIO Intelligence, 2012). There is a marginal cost to button cell manufacturers for investments in Research and Development (R&D) and assembly line adaptations and these costs are likely to be passed on by retailers to consumers which, is expected to be reflected in an increase in retail price by 5-10%.

The Lowell Centre for Sustainable Production in Massachusetts conducted a study in 2011 on the economics of converting to mercury-free products including button cell batteries, and found that maintenance of dual production capability between mercury and non-mercury products creates inefficiencies increasing the cost of production (Lowell Centre for Sustainable Products, 2011).

There are economic benefits to waste collectors and recyclers from mercury-free alternatives in the form of a 30-40% lower cost of recycling button cell waste (BIO Intelligence, 2012).

Health/Environmental Risks and benefits of non-mercury alternatives

In the EU, it was estimated that in 2009, 88% of button cell batteries were not collected for separate waste collection and as such would have been disposed in landfills or incinerated. This represented an estimated 4.5 tonnes of mercury going to disposal.

Due to the difficulty in increasing separate waste collection rates of batteries, substitution of mercury with alternatives is the most effective way of reducing this environmental impact.

A prohibition of mercury-containing button cell batteries would reduce exposure of global citizens to mercury introduced to the environment from this product.

Examples of regional or national restrictions

Mercury has already been eliminated from most batteries (e.g. mercuric oxide batteries) in the EU as a result of restrictions imposed by Directive 2006/66/EC on batteries and accumulators and waste batteries and accumulators (Batteries Directive), which prohibits the placing on the market of batteries and accumulators containing more than 0.0005% Hg by weight. This threshold intends to cover trace contamination and reflects current measurement limitations. Mercury-containing batteries are classified as hazardous waste but only a certain proportion are required to be separately collected for further recycling (45% since 2016) by the Directive.

In 1996, the USA introduced a national ban on mercury oxide batteries, after which a number of states implemented a ban on all types of mercury containing button cell batteries including Connecticut and Maine, Rhode Island, Louisiana, Wisconsin and Illinois (Lowell Centre for Sustainable Products, 2011).

In 2011, China issued ‘Clean Production Guidelines’ for the battery sector, including recommendations that companies actively promote mercury-free button cells. Mercury content of zinc button cell batteries produced in China has been 0.005 mg per battery (0.25%) since 2013 (Lin et al., 2016). In 2017, the Chinese Ministry of Environmental Protection issued a mercury regulation that states that from 2021 mercury-containing batteries are prohibited, but includes the Minamata exemption for zinc-silver oxide and zinc air batteries containing less than 2% mercury (CIRS-REACH, 2017).

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Compact fluorescent lamps (CFLs)

Summary Overview

Compact fluorescent lamps (CFLs) are energy-saving lamps, available in a wide range of wattages, types and sizes. In CFLs, the ballast can either be integrated into the lamp (CFL with ballast (CFL.i) or separated from the lamp (CFL without ballast (CFL.ni)) (Gensch, et al., 2016). CFLs are regularly used for both commercial (i.e. retail, office, hospitality and leisure premises) and residential use, as energy-saving alternatives to incandescent lights (Gensch, et al., 2016). CFL.is are screw-based lamps which can be directly connected to 230V and 110V lightbulb sockets (e.g. E27). CFL.nis can only operate as spare parts in a luminaire, which contain a specific electronic driver or ballast.

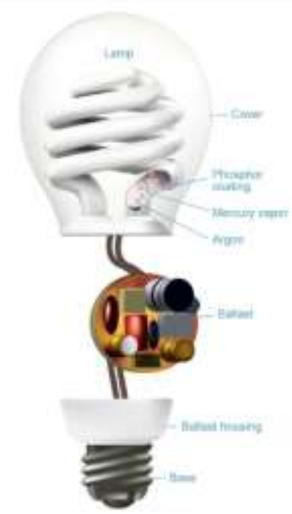
Under Part 1 of Annex A of the Minamata Convention, CFLs 'for general lighting purposes that are ≤ 30 watts with a mercury content exceeding 5 mg per lamp burner' are subject to Article 4, paragraph 1. As such, the manufacture, import and export of these products is no longer permitted from 2020. However, Parties with a registered exemption granted under Article 6, are not subject to the phase-out date of 2020 (UNEP, 2013a).

LEDs are the most suitable alternative to several types of CFLs, as incandescent lights and halogens consume more energy than CFLs over their lifetime. For many use cases, the industry agrees that LEDs provide an appropriate alternative for several types of CFLs, offering a longer lifetime (in some cases) and enhanced energy efficiency. Regarding, economic feasibility, LEDs bear greater upfront costs than CFL.is. Nevertheless, higher energy efficiency and a longer lifetime for some high-quality LED lamps suggests that LEDs can pay off in the long term. However, LED spare part alternatives for CFL.ni are not widely available, requiring a complete replacement of all installed CFL.ni based luminaires.

A number of countries already impose national limits on the mercury content in CFLs (both CFL.i and CFL.ni) that go beyond the requirements of the Minamata Convention (including the EU, the Russian Federation and India).

Technical description

Figure 2 – General composition of a CFL.i lamp (US EPA, 2019a)



A small amount of mercury is present in all CFL.is, as it is necessary for the low-pressure gas discharge (Gensch, et al., 2019). In CFL.is, ultraviolet light is generated by driving an electric current through a tube, which contains argon and mercury. This stimulates the phosphor coating to produce visible light. CFL.is initially require more energy when they are first turned on compared to alternative lamps, but they tend to use 70% less energy than incandescent bulbs on average. The ballast, which is visible in Figure 2, provides sufficient voltage to initially power the CFL, then regulates the current (US EPA, 2019a).

Mercury is considered vital to the conversion of electricity into ultraviolet light, which is then converted into visible light (Gensch, et al., 2019). Lighting Europe suggests that although alternatives to mercury in CFL.is, such as noble gases, were considered, they did not provide the same level of lamp performance in regard to lifetime, output or energy consumption (Lighting Europe, 2016).

Figure 3 – CFL.ni lamp

In CFL.nis, ultraviolet light is generated by driving an electric current through a tube, which contains argon and mercury. This stimulates the phosphor coating to produce visible light. CFL.nis initially require more energy when they are first turned on than alternative lamps, but they tend to use 70% less energy than incandescent bulbs on average.

CFL.nis are spare parts of luminaires, which require a variety of different electronic drivers included in the luminaire, enabling operation with different wattages, tube diameters, gas pressures and electrode pre-heating, resulting in application-related light distributions, efficiencies, dimming and lifetimes.

CFL.nis can be divided into normal life and long-life lamp types (>20 000 hours).

Range of mercury content/consumption per unit product

The average mercury content in CFLs has reduced by at least 20% over the past several years (US EPA, 2019b). In the USA, typical mercury content of CFLs is 0.9-4 mg per lamp (COWI and ICF, 2017).

Availability of non-mercury alternatives

Main alternatives: Light emitting diodes (LEDs), incandescent light bulbs, halogens

There are three potential alternatives to CFLs: LEDs, incandescent light bulbs and halogens.

Halogens and incandescent light bulbs consume a lot more energy than CFL.is, which is why countries are already phasing them out. In the EU they were banned from sale from September 2018 according to the EU energy regulations (RoHS Directive 2011/65/EU)

LEDs therefore offer the most suitable alternative to CFL.is. The lighting industry is evolving from a market primarily focused on discharge lamp technology to a market focused on LED technology (Gensch, et al., 2019) for general lighting purposes. In 2013, LEDs comprised only 5% of the market share in the EU, yet this is expected to increase to 60% by 2020 and 80% by 2030 for general lighting purposes. In the US and Canada, LEDs are also expected to gain market share, as they begin to displace CFL.is. Many retailers, such as Walmart, and manufacturers, such as General Electric, are moving away from the use and production of CFL.is altogether (COWI and ICF, 2017).

For CFL.nis however, the transition to LEDs is predicted to only be 8% by 2020. Beyond Europe, CFL.ni lamps will remain in the market, as spare parts for installed CFL.ni-based luminaires. Following the EU ban of halogen bulbs under Regulation (EC) No 244/2009 from January 2019, LED lamps are reported to be the only mercury-free technology on the European market (Gensch, et al., 2016). Incandescent light bulbs also do not comply with Regulation (EC) No 244/2009, and as such, the phasing out of inefficient incandescent light bulbs is already underway. There are also a number of new material options for LEDs, such as organic LEDs (OLEDs) and graphene lighting, which may replace the metal-based semiconductors more regularly used today. However, these are new to the market, and it is yet to be determined if their efficiency and lifecycle impacts will be preferable to LEDs (COWI and ICF, 2017).

Technical feasibility of mercury-free alternatives

The technical feasibility of retrofitting LEDs is lower for CFL.ni than for CFL.i.

According to information provided by an industry group during stakeholder engagement conducted for this study, CFL.ni lamps do not have adequate substitutes for the full portfolio of lamps. The industry group also states that a lack of control gear compatibility and the series of lamp bases available are likely to force users to replace the entire luminaire. However, CFL.nis comprise a relative minority of the market (The Lightbulb Company, 2019).

It is technically feasible to retrofit LEDs for CFL.is for general lighting purposes, although in some cases retrofit products are limited in their capacity to provide the same wattage and lumen output as CFLs (Gensch, et al., 2019). Regarding long-life CFL.is, it has been reported that there are limited LED alternatives available due to differences in weight, light distribution and shape (Lighting Europe (2017).

One technical issue with LEDs is their sensitivity to heat. If exposed to temperatures exceeding recommended levels, this can result in a reduction in the lifetime of the product (Gensch, et al., 2019). However, compared to competing technologies, LEDs bear significantly longer lifetimes, benefiting consumers as fewer purchases are required (COWI and ICF, 2017). In addition, relative to incandescent lighting, LEDs are 90% more efficient. Due to their longer lifetime, efficiency and directional nature, LEDs are particularly applicable to commercial settings (US EPA, 2019c). Increasingly, they are also being used in street lighting, garage lighting and for illuminating homes.

Regarding special purpose lamps, replacement by alternatives is expected to be less feasible, as these lamps tend to be tailor-made (COWI and ICF, 2017). In recent years, LEDs have been applied to some special purpose lighting applications. However, further developments are expected to be slower than general lighting applications.

According to information provided by an industry group, it is technically feasible to lower the mercury content in CFLs below Minamata maximum concentrations. In many countries, for example in the EU and Australia, the mercury content restriction on CFL.is is 50% lower than Minamata standards (2.5 mg per lamp compared with 5 mg per lamp under Minamata).

A study by the Swedish Energy Agency (2019) concluded that mercury-free alternatives have the technical feasibility to replace fluorescent lamps, enabling exemptions under Directive 2011/65/EU on the restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS Directive) for CFLs to be allowed to expire.

Economic feasibility of non-mercury alternatives

Table provides an overview of the lifetime, power rating, colour temperature, colour rendering and price of a range[1] of CFL.is and LEDs with varying forms and light intensities. Table does not provide a like-for-like comparison of available LEDs with existing CFL.is luminaires. However, the data displays that the lifetime, price, power rating and colour temperature and rendering are much more variable for LEDs than for CFL.is. LEDs have larger upfront costs than CFL.is, however, this is outweighed by higher energy efficiency and longer product life. Furthermore, prices for LEDs have displayed a continuous downward trend since 2011 (LED Inside, 2018).

Table 1 – Comparison of lamp specifications and prices for CFL.is and LEDs (Gensch, et al., 2019)

	CFLi	LED
Lifetime	20 000 hours	20 000 – 50 000 hours
Power rating (range)	10 – 18 W	3,9 – 21 W
Colour temperature	2500 – 2700°K	2100 – 4500°K
Colour rendering CRI (Ra)	80 – 82	80 – 97
Price (€)	9,5 – 18 €	7,5 – 33,5 €

Table 2 provides an estimation, produced by Lighting Europe (2017), of replacement costs of all CFL.nis on the market. The table highlights that there are labour costs involved with the replacement of some CFL.ni fixtures, where the luminaire requires rewiring or conversion.

The Swedish Energy Agency (2019) however found that it is cost-effective to replace CFL.nis with LEDs, finding that LED replacements for CFL.nis offer a quick payback period of between 1.3-3 years, and have the capacity to last 2-3 times longer than CFL.nis. These calculations however did not include labour costs of replacement.

Table 1 – Replacement costs of all CFL.nis on the market (Lighting Europe, 2017)

<table>
<tr><th colspan="5">Lamps on the market in the commercial, industrial and public sector:</th></tr>
<tr><td>Lamp type</td><td>Lamps on the market</td><td>Lamps/fixture</td><td colspan="2">Fixtures</td></tr>
<tr><td>CFL.ni</td><td>619 000 000</td><td>1,5</td><td colspan="2">412 666 667</td></tr>
<tr><th colspan="5">Replacement with LED retrofit, share and costs</th></tr>
<tr><td>Lamp type</td><td>Retrofit share</td><td>Product costs</td><td>Labour costs</td><td>Total costs</td></tr>
<tr><td>CFL.ni</td><td>10%</td><td>12,5 €</td><td>20 €</td><td>30 €</td></tr>
<tr><th colspan="5">Replacement with LED luminaire, share and costs:</th></tr>
<tr><td>Lamp type</td><td>Retrofit share</td><td>Product costs</td><td>Labour costs</td><td>Total costs</td></tr>
<tr><td>CFL.ni</td><td>90%</td><td>75 €</td><td>25 €</td><td>100 €</td></tr>
<tr><th colspan="5">Total replacement costs:</th></tr>
<tr><td>Lamp type</td><td>Retrofit</td><td>LED luminaire</td><td colspan="2">Total costs</td></tr>
<tr><td>CFL.ni</td><td>1 341 166 667 €</td><td>37 140 000 000 €</td><td colspan="2">38 481 166 667 €</td></tr>
</table>

Health/Environmental Risks and benefits of non-mercury alternatives

LEDs are mercury-free and are accepted to have improved energy efficiency compared with CFLs. End-of-life management should consider the copper, nickel and lead content in LEDs due to their hazardous nature and consider to utilise these resources (Seong-Rim, et al., 2011). However, the use of non-mercury alternatives ensures limiting the amount of mercury released to the environment including during the end-of-life phase.

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[1] The ranges are based on 5 long-life CFLi and 10 LED alternatives, based on data provided by Philips and Osram websites.

Examples of regional or national restrictions

In Europe, Regulation (EU) 2017/852 on mercury, Directive 2011/65/EU on the restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS Directive) and the Minamata Convention are of the greatest relevance to CFL.is and associated alternatives.

Error! Reference source not found. provides a summary of the CFLs regulated under EU legislation, but not under the Minamata Convention. From December 2018, under Article 5 of Regulation (EU) 2017/852, the manufacture, import and export of CFLs for general lighting purposes for 'CFLi ≤ 30 watts with a mercury content exceeding 2.5 mg per lamp burner' is prohibited in the EU. In addition, the RoHS Directive has prohibited the placing of some CFLs exceeding 5mg Hg on the market since December 2011, and CFLs exceeding 2.5mg since December 2012 (Annex III, exemption 1 (a)-(e) and 1(g)).

From 1 September 2021, under Regulation (EU) 2019/2020 on the eco-design requirements for light sources and separate control gears, the declared power consumption of a light source will be obliged to not exceed the maximum allowed power, based on specified values for threshold efficacy and end loss factors in Annex II. According to information provided by the European Commission, is unclear whether CFLs will be able to meet these efficiency requirements.

Canada has also implemented national regulations for products containing mercury. CFLs for general lighting purposes ≤ 25 W have a maximum mercury content of 4 mg per lamp. In addition, CFLs > 25 W have a maximum mercury content of 5 mg per lamp (Minister of Justice, 2019). It should be noted that this is for different wattages than those prescribed by the Minamata Convention and so is not directly comparable.

Table 2 – CFLs regulated by EU legislation but not under the Minamata Convention

Product	Extent of EU restriction	Relevant EU Legislation	Minamata Convention
Single capped (Compact) fluorescent lamps (CFL) for general lighting purposes < 30 W	≤ 2.5 mg per lamp burner	Directive 2011/65/EU (RoHS), Exemption 1(a)g Regulation (EU) 2017/852	≤ 5 mg per lamp burner (all CFL)
CFL for general lighting purposes ≥ 30 < 50 W	≤ 3.5 mg per lamp burner	Directive 2011/65/EU (RoHS) Regulation (EU) 2017/852	Not regulated
CFL for general lighting purposes ≥ 50 W and < 150 W	≤ 5 mg per lamp burner	Directive 2011/65/EU (RoHS)	Not regulated
CFL for general lighting purposes ≥ 150 W	≤ 15 mg per lamp burner	Directive 2011/65/EU (RoHS)	Not regulated
CFL for general lighting purposes with circular or square structural shape and tube diameter ≤ 17 mm	≤ 7 mg per lamp burner	Directive 2011/65/EU (RoHS)	Not regulated
CFL for special purposes	≤ 5 mg per lamp burner	Directive 2011/65/EU (RoHS)	Not regulated
CFL for general lighting purposes < 30 W with a lifetime	≤ 3.5 mg per lamp burner	Directive 2011/65/EU (RoHS)	Not regulated

equal or above 20 000 h			

Australia has implemented the E3 Programme, which reduces the maximum mercury content of CFLs < 30 W to 2,5 mg. As 80% of products were already in compliance prior to policy implementation, this did not have a significant impact on suppliers (Energy Rating, 2017).

The US enforces standards in the lighting industry through the Energy Star programme, introducing a limit of 2,5 mg for CFLs ≤ 23 W and 3 mg for CFLs > 23 W (UNEP, 2013b).

In Russia and the Eurasian Economic Union (EAEU), Technical Rule EAEU 037/2016 on the restriction of the use of hazardous substances in electrical and radio electronic products placed restrictions on CFLs that go beyond Minamata and are equivalent to those placed by the European RoHS Directive shown in **Error! Reference source not found.**. Namely, 2.5 mg for CFL <30 W, 3.5 mg for 30-50 W, 5 mg for 50-150 W, 15 mg for >150 W, 7 mg for circular or square bulbs, and 5 mg for lamps for special purposes.

The same restrictions for CFLs have been put into force in India (G.S.R338(E) E-Waste (Management) Rules, 2016) (Gazette of India, 2016). At the same time, there has been a gradual discontinuation of manufacturing CFLs in India since 2014. This has been matched by a gradual increase in the sales of LED lamps in the same period (**Error! Reference source not found.**).

Table 3 – Quantity of lamps sold in India per year by type (million units)

Lamp type	2014	2015	2016	2017	2018
CFL	450	381	205	102	28
LED	4-86	62	251	336	520

In addition, information from an industry body stated that more stringent mercury levels than Minamata, based on the EU RoHS Directive, are implemented in further countries and regions, including Singapore, Thailand, Ukraine, Jordan, Turkey, UAE, Saudi Arabia, Vietnam, South Korea and Japan.

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Linear Fluorescent Lamps (LFLs)

Summary Overview

Linear Fluorescent Lamps (LFLs) are functionally identical to compact fluorescent lamps (CFLs). They are denoted as linear due to their shape and are used in a range of applications from domestic use to professional and industrial buildings. In 2016, LFLs were reported to be used in hundreds of millions of lighting installations (Gensch, et al., 2016).

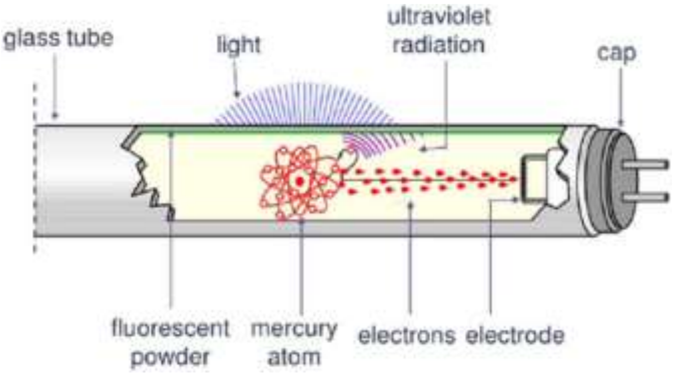
Under the Minamata Convention, LFLs for general lighting purposes are restricted to 5 mg per lamp for triband phosphor lamps below 60 watts, with a phase-out date of 2020 for all lamps above the mercury limits. Halophosphate LFLs under 40 watts for general lighting purposes are restricted to 10 mg per lamp, with a phase-out date of 2020 for all lamps above these mercury limits. In Europe, halophosphate lamps have been phased out, although there is evidence they are still being produced and exported from the EU (COWI & ICF, 2017).

LEDs are the most suitable alternative to LFLs, with increasing levels of usage and development. With the exception of long-life LFLs, LEDs have environmental benefits of increased product lifetime to LFLs. Tubular LED lamps are available for most sizes of LFLs with the exception of T2 bulbs (~7mm diameter). Also for certain other diameters, notably T5 (9-17mm) and T8 (17-28mm), stakeholders provide conflicting information as to the availability and feasibility of LED alternatives, however it is now claimed that substituting LEDs is suitable (Gensch, et al., 2016) (SEA, 2019). Also for certain diameters, notably T5 (9-17mm) and T8 (17-28mm), there have been discussions as to the availability and feasibility of LED alternatives, In addition to substitution with non-mercury LEDs, halophoslate lamps can be replaced with triband phosphor LFLs, which have a lower mercury content.

Available studies indicate that substitution with LEDs is possible from a technological standpoint but might lead to significant socio-economic impact, depending on market availability of plug-in alternatives (Gensch, et al., 2016) (SEA, 2019). At the time of drafting this fiche, an assessment of that conflicting information by the European Commission is ongoing. This fiche therefore provides information on the conflicting views but does not conclude on the matter.

Technical Description

Figure 4 – Linear Fluorescent Lamp (Sethurajan et al., 2019)



In LFLs, ultraviolet light is generated by driving an electric current through a tube, which contains argon and mercury. This then stimulates the phosphor coating to produce visible light. LFLs are categorised based on the type of phosphor used. Triband phosphor lamps utilise three combined materials with peaks at blue green and orange lights to create an overall white hue. They are a technical successor of halophosphate lamps.

LFLs are split into different categories based on tube diameter. T2 LFLs (where the 'T' represents a tubular lamp, and the number represents the diameter) are a small segment of the market for energy efficient lamps, being used in private homes as well as professional use. T5 lamps are used mainly in professional areas such as offices and industrial buildings. T2, T5 and T8 lamps are operated with electronic control gears (ECG) which have advantages over conventional control gears (CCG) regarding power consumption, lifetime and maintenance costs. Long lifetime lamps are another type produced with lifetimes over 25,000 hours. T8 lamps have a diameter of 26mm and come in 16 different lengths, with high energy efficiency of up to 100 lumens per watt and a lifetime of 20,000 hours. Long-life LFLs have more Hg per lamp due to the mercury using process taking place for longer, however there is less Hg per lumen hour of operation compared with lamps of lower life (Gensch, et al., 2016).

Range of mercury content/consumption per unit product

The average mercury content of a triband phosphor T2 LFL is 1.5-3.5 mg (Lighting Europe, 2015).

The average mercury content of a triband phosphor T8 LFL is 2.5 - 3.3 mg

The average mercury content of a triband phosphor T5 LFL is 1.5 - 2.6 mg (Gensch, et al., 2016).

The average mercury content of a halophosphate LFL 8-10 mg (COWI&ICF, 2017)

Availability of non-mercury alternatives

Main alternatives: Tubular LED lamps based on Light emitting diodes (LEDs)

LED replacements are available for T8 LFLs, however the compatibility of the component (LED lamp) with the electrical system (installed in LFL luminaire) can have limitations that are expected to be resolved in ongoing research, such as low lumen output and low Colour Rendering Index (CRI)[2] (VHK & VITO, 2015). Information published by the Swedish Energy Authority indicates that in 2019, there are LED bulbs engineered to operate in existing T8 ballasts while minimising labour and recycling costs (SEA, 2019).

According to industry sources, there are almost no T2 lamps available based on LED technology that are a direct replacement for T2 lamps in existing applications. Based on previous findings there are still relatively few T5 products based on LED technology, however this is challenged by the recent SEA study which argues that T5 luminaires can easily be updated to LEDs (Gensch, et al., 2016) (SEA, 2019).

Halophosphate lamps can be replaced by triband phosphor lamps with a lower mercury content in cases where mercury-free alternatives are not yet feasible. Triband phosphor LFLs are subject to more stringent mercury concentration restrictions of 3-5mg depending on bulb size, while halophosphate lamps, now phased out in Europe, previously had limits set at 10mg.

Technical feasibility of mercury-free alternatives

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[2] An industry scale from 0-100 indicating how accurate a given light source is at rendering colour when compared to a reference light source

Tubular LED lamps and luminaires are entering the market for replacing certain mainstream LFLs, matching LFLs for efficacy, energy efficiency, and appearance. However, there are limited T2 LED lamps available on the market (Lighting Europe, 2015).

Tubular LED lamps for T8 replacement are only available for mainstream application in 3 lengths (600, 1200, 1500mm) and in the most common colour temperatures (i.e. not very cool 12000K or very warm 2700K) (Gensch, et al., 2016). The more recent SEA study (2019) argues, however, that both T5 and T8 retrofit LEDs would be technically feasible to replace LFLs, without the need for rewiring. T8 LEDs are omnidirectional while LED tube lamps emit light directionally, resulting in higher glare levels and lower uniformity of lighting levels (Lighting Europe, 2015).

Mercury levels in triband phosphor LFLs that can replace halophosphate LFLs are restricted to levels lower than that of Minamata. This indicates that there are no technical feasibility issues associated with reducing mercury content to these levels (see Examples of regional or national restrictions).

From 1 September 2021 (and 1 September 2023 in the case of certain sizes of T8 bulbs), under Regulation (EU) 2019/2020 on the eco-design requirements for light sources and separate control gears, the declared power consumption of a light source will be obliged to not exceed the maximum allowed power, based on specified values for threshold efficacy and end-loss factors in Annex II. According to information provided by the European Commission, it is unclear whether T8 LFLs will be able to meet these efficiency requirements.

Economic feasibility of non-mercury alternatives

If fluorescent lamps would not be available and there would be no plug-in alternative, then the need to replace luminaires, control gears, or complete lighting systems etc. would result in high investment costs for businesses (Gensch, et al., 2016). The socio-economic impact report, published recently by the EU Commission, states that the related costs are substantial: 130-250 Billion € (European Commission, 2019). The sectors involved with the replacement (lamp producers, lighting installation contractors, etc.) would have benefits. However, from an overall economic perspective, premature replacement means a loss of capital and generation of 1-6 Million tonnes of waste (EU commission 2019). Therefore, a phase-out that replaces lamps at their natural end-of-life would avoid these impacts.

According to an industry group, LED alternatives are more expensive than conventional LFLs. However, information published by SEA (2019) indicates that the payback period for replacing T8 LFLs with LED retrofits is between 5 and 11 months from saved electricity, with a service life that is 1.5 to 2.5 times longer, and for T5 LFLs the payback time for LED replacements is 3 to 3.5 years (SEA, 2019).

Health/Environmental Risks and benefits of non-mercury alternatives

The phase-out of halophosphate LFLs in the EU (in favour of tri-band phosphor lamps) resulted in a 53% decrease in mercury per lamp (Lighting Europe, 2015).

There are currently no studies comparing LFLs with LEDs in a life cycle analysis for environmental impacts, however CFLs (functionally similar to LFLs) and LEDs have been shown to be equivalent as early as 2012 (Gensch, et al., 2016). For T5 lamps, LED tubes are nearly at the same level of environmental performance as LFLs according to the European Environment Bureau (Gensch, et al., 2016).

According to SEA (2019), restriction of T5 and T8 LFLs from 2021 in the EU would result in a saving of 40.9 million metric tonnes of CO_2 due to reduced energy consumption.

Examples of regional or national restrictions

For triband phosphor LFLs in Europe, Directive 2011/65/EU on the restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS Directive) places restrictions on mercury in LFLs that are more specific than the Minamata Convention based on lamp diameter. Double-capped LFLs are subject to an exemption and subject to the following restrictions:

- Tri-band phosphor with normal lifetime and a tube diameter < 9 mm (e.g. T2): 4 mg
- Tri-band phosphor with normal lifetime and a tube diameter ≥ 9 mm and ≤ 17 mm (e.g. T5): 3 mg
- Tri-band phosphor with normal lifetime and a tube diameter > 17 mm and ≤ 28 mm (e.g. T8): 3.5 mg
- Tri-band phosphor with normal lifetime and a tube diameter > 28 mm (e.g. T12): 3.5 mg
- Tri-band phosphor with long lifetime (≥ 25 000 h): 5 mg

Russia and the Eurasian Economic Union (Technical Rule EAEU 037/2016) as well as India (G.S.R338(E) E-Waste (Management) Rules, 2016) set lower limits on triband phosphor LFLs than required by Minamata. Limits set are the same as those prescribed by the EU RoHS Directive, as outlined above. There are a number of other countries that have also adopted RoHS-like restrictions setting the same limits on triband phosphor LFLs.

In Europe, placing on the market of halophosphate LFLs has been effectively prohibited since 2012 when the exemption under Directive 2011/65/EU on the restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS Directive) expired.

Many nations have implemented RoHS-like legislation, which bans mercury-containing LFLs. In Russia and the Eurasian Economic Union (EAEU), Technical Rule EAEU 037/2016 on the restriction of the use of hazardous substances in electrical and radio electronic products are some such examples, and India, Singapore, Thailand, Ukraine, Jordan, Turkey, UAE, Saudi Arabia, Vietnam, South Korea and Japan are examples of other nations implementing RoHS-like legislation which bans mercury-containing halophosphates.

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High-Pressure Sodium Lamps

Summary Overview

High-pressure sodium lamps (HPS) are used in multiple industrial applications, such as in large-scale manufacturing and plant cultivation. They are also used for outdoor area lighting such as roads, car parks and security areas.

Currently, under the Minamata Convention, there are no restrictions applicable to mercury in high-pressure sodium lamps for general lighting purposes.

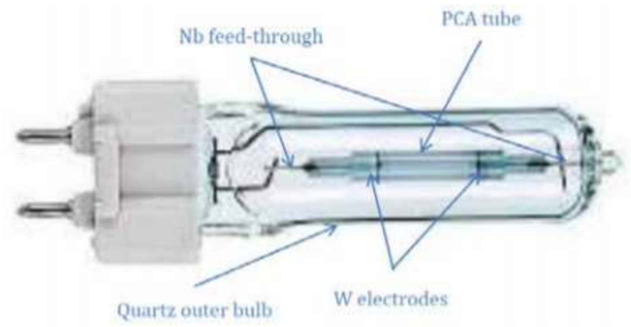
An estimated 5-10 kg of mercury are brought into the market in HPS lamps per annum in Europe (Lighting Europe, 2015). The main alternative to high-pressure sodium lamps are LEDs, which are not compatible with existing luminaires and as such require a complete replacement. LEDs are increasingly being used in outdoor lighting where HPS lamps are commonly applied, with LEDs projected to reach 89% of global market share of streetlights by 2027 (Northeast Group, 2017). It has been estimated that combined impacts of global warming potential, respiratory effects and ecotoxicity of LED lamps are 30% lower compared to high-pressure sodium lamps for street lighting and other outdoor applications (European Environment Bureau, 2015).

In the EU, the quantity of mercury in HPS bulbs is restricted based on the lamp wattage.

Technical Description

HPS lamps consist of a cylindrical discharge tubes made of poly-crystalline alumina (PCA), in which two electrode assemblies are mounted at each side (Figure 5) (Gensch et al., 2016).

Figure 5 – HPS lamp (Gensch et al., 2016)



The electrodes are made of tungsten in the shape of a rod, sometimes with coiled windings. Tungsten electrodes are welded to niobium tubes that serve as the electrical feed-through. Inside the discharge tube, xenon is present as a buffer gas. Mercury is dosed in the discharge tube as sodium mercury. The quantity of mercury used per lamp depends on lamp power and optical performance.

A high voltage pulse is supplied to the electrode, breaking down the xenon gas and allowing a current to flow through the resulting plasma. The heat released by the discharge warms up the tube and evaporates the sodium and mercury.

HPS lamps with increased colour rendering are typically used for outdoor applications where colour rendering is important, such as city centres and parking lots, or indoors in shops where products are displayed in a certain light. The role of mercury in these lamps is to tune the plasma resistance to optimise efficiency - thermal conduction is reduced and as such there is less heat loss from the plasma. The mercury vapour pressure increases the electrical resistance in the discharge which enables putting more power into the discharge, causing sodium and mercury to evaporate further. Additionally, the presence of mercury causes the lamp to have high red rendering properties.

The mercury is not consumed in the lamp’s life; as the sodium reacts, the fraction of mercury in the amalgam therefore becomes higher over time.

Range of mercury content/consumption (per unit product

10-50 mg (3-40mg for lamps with improved colour rendering index Ra>60)

Availability of non-mercury alternatives

Main alternatives: LED Lamps, unsaturated vapour HPS lamp, Xenon HPS Lamp

Mercury can be replaced with xenon in HPS bulbs; however, there are effects on colour warmth (see technical feasibility of mercury alternatives).

HPS lamps can be operated in an unsaturated vapour mode, where all Hg/Na amalgam are vaporised, as such a smaller mercury dosage is needed. This has benefits such as better voltage and power stability and faster warm-up, however there are technical limitations such as increased rate of sodium loss leading to changes in lamp colour properties.

LED lamps offer a number of benefits as an alternative to HPS, notably energy efficiency, longer product life, and absence of mercury. LED luminaires are increasingly being used in outdoor lighting where HPS lamps are commonly applied, with LEDs projected to reach 89% of global market share of streetlights by 2027 (Northeast Group, 2017).

Technical feasibility of mercury-free alternatives

Replacement of Hg with Xenon in HPS lamps broadens the colour spectrum and therefore does not have the effect of a warm colour, and additionally requires very high pressures, which would hinder current ignition technology.

Investigations into unsaturated vapour modes for lamps in which all sodium and mercury would be in vapour state in operation did not result in products with reduced Hg.

LED luminaires are increasingly being made to replace HPS lamps and are expected to increase in this application. It has been demonstrated that these are suitable for Colour Rendering Index (CRI) at least up to 85 and as such are suitable to replace HPS in new installations for most applications, i.e. with the exception of those which require CRI >85. There are limitations to substitution of HPS with LED in existing installations due to different dimensions (Gensch et al., 2016).

Economic feasibility of non-mercury alternatives

Industry has argued that there is an increase in fixed costs associated with substitution of mercury containing HPS lamps, loss of jobs from HPS manufacturing in Belgium and Hungary, and loss of application from different colour characteristics of Hg-free alternatives (Lighting Europe, 2015).

LEDs have larger upfront costs than HPS (Lighting Europe, 2015). However, LEDs have other economic benefits such as longer life and less energy usage. LED replacement lamps can use 50% less energy than HPS and last 50,000 hours compared to the 24,000 hour HID bulbs they replace (European Environment Bureau, 2015).

Health/Environmental Risks and benefits of non-mercury alternatives

It has been estimated that there are 5-10 kg of mercury brought into the market in HPS lamps per annum in Europe (Lighting Europe, 2015). Reduced energy consumption from increased LED efficiency will result in lowered energy consumption and hence burning of fossil fuels. A total life-cycle assessment was conducted by Dale et al. (2011), finding that impacts of global warming potential, respiratory effects and ecotoxicity of LED lamps are 30% lower compared to high-pressure sodium and metal halide luminaires for street lighting and other outdoor applications (European Environment Bureau, 2015).

LED replacements are not compatible with existing luminaires, and as such, a complete replacement is required. It is argued therefore that to minimise environmental impacts, early end-of-life of existing HPS luminaires must be avoided and lamps must be phased out at their natural end-of-life (European Environment Bureau, 2015). If this is to be the case then replacement HPS bulbs will need to be available until luminaires are replaced.

Examples of regional or national restrictions

High-pressure sodium lamps subject to restrictions under Directive 2011/65/EU on the restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS Directive):

- Mercury in High-Pressure Sodium (vapour) lamps for general lighting purposes not exceeding (per burner) in lamps with improved CRI Ra>60:
  - ≤ 155W: 30mg
  - >155W: 40mg
- Mercury in other High-Pressure Sodium (vapour lamps) for general lighting purposes not exceeding (per burner):
  - ≤ 155W: 25mg
  - 155W-405W: 30mg
  - >405W: 40mg

High pressure sodium lamps <155W are still available on the market in the EU, however lamps >405W are no longer available.

In the USA, the Interstate Mercury Education and Reduction Clearinghouse (IMERC) provides technical assistance to states that have enacted mercury education and reduction legislation. Some IMERC state members have enacted restrictions on the sale and distribution of mercury-containing lamps, such as in Connecticut (>100 mg) (IMERC, 2015). According to the EPA regulation the Universal Waste Rule (UWR), all mercury containing lamps must be managed as hazardous waste.

A number of Member States have passed RoHS- like regulations, which include the regulation of mercury-containing lamps. These include India, Russia and the Eurasian Economic Union, Japan, South Korea, Turkey and Vietnam (Chemical Watch, 2016).

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Other Fluorescent Lamps

Summary Overview

This fiche covers the category of ‘Other fluorescent lamps’ which covers lamps used in professional and consumer applications for purposes other than lighting, including bug zappers, certain ultraviolet lights (e.g. tanning lamps, black lights) and induction lamps. These lamps differ from lighting used for general lighting purposes by the use of different glass and phosphors, different technology, wattage, and size, and typically emitting in UV or blue wavelengths (Gensch, et al., 2016). Ultraviolet light is the part of the electromagnetic spectrum between visible light and X-ray radiation, i.e. between 100 and 400 nm. Due to their significance in industrial and residential use, and their separation in legislative documents, CFLs for lighting purposes are covered by a separate fiche.

Other fluorescent lamps are not currently covered by the Minamata Convention (UNEP, 2013).

The main alternative to mercury containing fluorescent lights are LEDs. LEDs have been claimed by lighting industry to be less capable of producing light in the non-visible UV range utilised by lamps in this category, operating at lower energy efficiency than CFLs (Gensch, et al., 2016). It was estimated by LightingEurope that 2kg of mercury entered European markets in 2016 from other fluorescent lamps of this kind (Gensch, et al., 2016).

There is scope to reduce the maximum mercury content for other discharge lamps for other general lighting and special purposes, as in the EU, to 15mg per lamp.

According to LightingEurope, Europe’s lighting industry association, single ended CFLs for special purpose lamps of this type account for 0.1% of total CFL sales in the EU or about 400,000 lamps per annum.

Technical Description

Fluorescent lamps operate at a low gas pressure. They produce light when an electric current passes between electrodes in a tube filled with low-pressure mercury vapour and inert gases. The electric current excites the mercury vapour in the tube, generating radiation primarily in the ultraviolet range. Fluorescent lamps covered by this fiche are not used primarily for lighting and include (NEWMOA, 2014):

- **Bug zappers** which contain a fluorescent lamp that emits UV light to attract insects.
- **Black lights** which use a phosphor to convert short-wave UV light in the tube to long-range UV that is used for forensic applications, special effects lighting and testing devices.
- **Tanning lamps** which use phosphor to emit mainly UV-A light and a small amount of UV-B light.
- **Lamps for the treatment of skin conditions** e.g. eczema, psoriasis, acne, vitamin D deficiency.
- **Induction lamps** are used in outdoor and factory lighting applications.

Figure 6 – Examples of applications of 'other fluorescent lamps' (Gensch, et al., 2016)

Range of mercury content/ consumption per unit product

Varies depending on lamp, estimated 2 kg of mercury entering the EU per annum (Gensch, et al., 2016).

Availability of non-mercury alternatives

Main alternatives: LED Lamps, dielectric barrier discharge (DBD) lamps

According to Gensch et al. (2016), no research is being performed into improvements of CFL technology with regard to mercury content and as such LED technology is the primary alternative. LEDs are increasingly available for general lighting solutions, however special purpose lamps are a niche market where development of LED alternatives has been slower (Gensch, et al., 2016).

It was stated by an industry group that in 2019 for blacklight blue, insect traps and tanning beds it is still the case that LED technology is lacking in non-visible UV light. It was however indicated that UVA/B technology based on integrated LED modules are in development which may be possible to replace HPS lamps in some applications. For medical applications, there are no alternatives approved by medical authorities (e.g. for psoriasis and acne treatment).

Technical feasibility of mercury-free alternatives

LEDs primarily emit only in the visible light spectra and so for applications where the main function of the lamp is to produce light in the non-visible UV range, such as tanning beds, lamps for the treatment of skin conditions, black lights and insect traps, LEDs do not provide comparable performance due to insufficient wall-plug efficiency and non-comparable spectral output. It is possible to produce LEDs with the required non-visible UV light spectra using AlGaN-LED technology however efficiency is lower (Gensch, et al., 2016):

- For UV-C and UB-B LEDs (100-315 nm) energy efficiency is currently lower than CFL
- For UV-A LEDs (315-400 nm) efficiency is below 380 nm spectral output

There are no comprehensive test results available comparing CFL-based equipment with LED-based equipment for effectiveness. The most important application of UV lamps is in tanning devices, with an estimated 50,000 tanning facilities in the EU (Gensch, et al., 2016).

There are potential limitations to the application of LED UV lamps due to the fact that CFL lamps radiate generated heat away naturally while LED lamps require heat to be transported away by conduction (Gensch, et al., 2016).

In the case of lamps for the treatment of skin conditions, alternatives will require comprehensive testing before use on humans, and light wavelength is important for the treatment to be effective.

Economic feasibility of non-mercury alternatives

The replacement of most specialist lamps will require a replacement of the equipment ballast, requiring appropriate care to ensure resources are recycled where possible and at the equipment’s natural end-of-life (Gensch, et al., 2016).

For emitting UV light LEDs are currently less energy efficient than CFL and so energy costs may be higher (Gensch, et al., 2016).

Health/Environmental Risks and benefits of non-mercury alternatives

A general concern with the phase-out of mercury containing fluorescent lamps in favour of LEDs is the cause of early end-of-life of installations including luminaires, which causes resources in these products to not serve their planned product life potential (Gensch, et al., 2016).

Examples of regional or national restrictions

In Europe, there is an exemption for other discharge lamps for special purposes with a mercury content above 15mg per lamp in the Directive 2011/65/EC (Restriction of Hazardous Substances (RoHS) Directive). The exemption has a validity period from 2021-2024, depending on devices.

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Non-fluorescent low-pressure discharge lamps

Summary Overview

Non-fluorescent low-pressure discharge lamps are lamps which emit ultraviolet C (UVC) radiation, without a phosphor coating (Gensch, et al., 2016). UVC radiation spans the wavelengths 100 – 280 nm. Lamps emitting at a higher wavelength are coated with phosphor, and do not fall under this category (Helios Quartz, 2016). Non-fluorescent low-pressure discharge lamps include ultraviolet lamps, UVC Compact Fluorescent Lamps (CFLs) and quartz ultraviolet amalgam lamps. Non-fluorescent low-pressure discharge lamps are used in industrial, commercial and residential applications, primarily to reduce the spread of bacteria through disinfection.

Currently, non-fluorescent low-pressure discharge lamps are not covered by the Minamata Convention.

Innovation in recent years have displayed progress in the lifetime and power intensity of LED alternatives. These also have the potential to address the drawbacks of UVCs, which include fragility, a lack of portability and the contamination risk associated with disposal.

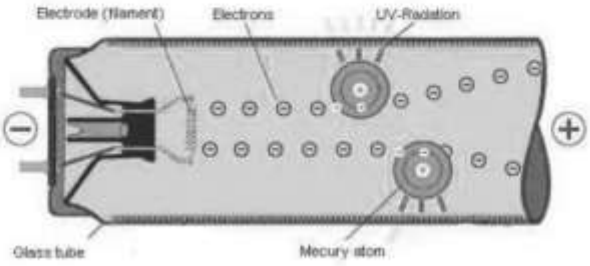
In the EU, Directive 2011/65/EC (Restriction of Hazardous Substances (RoHS) Directive) implements a limit on the mercury content of ‘other low pressure discharge lamps’ (≤ 15 mg). In addition, India, Thailand, Ukraine and the Eurasian Economic Community (EurAsEC) have implemented national legislation on the use of mercury in non-fluorescent low pressure discharge lamps. Further, Jordan, Turkey, UAE, Saudi Arabia, Vietnam and South Korea have adopted national legislation in line with the RoHS Directive. Therefore, there is scope to reduce the maximum mercury content for non-fluorescent discharge lamps, rather than replacing these lamps with UVC LEDs alternatives. Gensch et al. (2016) also declare that a 15 mg limit is feasible, as multiple EU and non-EU manufacturers already produce compliant lamps.

Technical Description

Non-fluorescent low-pressure discharge lamps do not produce visible light and therefore, are not used for illumination purposes. Instead, these lamps are primarily used in germicidal applications, to reduce the spread of microorganisms. The use cases for these lamps include the ultraviolet germicidal disinfection of drinking water, waste water and beverages. In addition, these lamps are used for air disinfection units, aquaculture and fish farming applications, and the disinfection of surfaces (Gensch, et al., 2016). Germicidal effectiveness is primarily determined by wavelength, duration of exposure and the power intensity of UV light (Lux Review, 2017).

In non-fluorescent low-pressure discharge lamps, a small amount of mercury is required to enable the lamp to function. As the electric current flows through the discharge tube between the electrodes, the electrons cause the mercury atoms to produce short-wave ultraviolet radiation, as displayed in **Error! Reference source not found.**. According to ISO Standard ISO-12348, these lamps enable transmission of light in the UVC region of 100 nm – 280 nm. Some UVC wavelengths are blocked by specific glass types. However, the use of synthetic quartz allows wavelengths as low as 185 nm to pass, as quartz is highly transparent to UVC radiation (Helios Quartz, 2016).

Figure 7 – Non-fluorescent low pressure discharge lamp (Lighting Europe, 2015a)



The use cases are highly specialised, resulting in a variety of sizes, power levels and end cap configurations depending on the specific application. In addition, the power ranges vary from 1 W to

1000 W and the operating temperature can range from 0˚C to 100˚C. In some cases, thermal control may be necessary (Gensch at al., 2016).

Range of mercury content/ consumption per unit product

The average mercury content for lamps falling under exemption from the RoHS ‘mercury in other low-pressure discharge lamps’ is 4 mg – 15 mg (Gensch, et al., 2016). This upper limit of the range is largely linked to compliance with the RoHS, which places a 15 mg limit on non-fluorescent low-pressure discharge lamps. However, a number of manufacturers, which have operations outside Europe, also comply with the RoHS 15 mg limit (Van der Meer, et al., 2015).

Availability of non-mercury alternatives

Main alternatives: UVC LEDs

Despite the positive attributes of mercury UVCs (i.e. the ease of application, and lack of toxic by-products relative to chemical disinfection), these lamps are fragile, lack portability and in some cases, display a limited lifetime (University of Cambridge, 2019). Therefore, alternatives can address these drawbacks as well as bypassing the mercury contamination risk associated with disposal.

The most promising alternative to mercury UVCs are UVC LEDs. In particular, UVC LEDs which use aluminium gallium nitride (AlGaN), have become an effective alternative in recent years, due to their long lifetime, low voltage and relatively compact nature (Guo, et al., 2018).

According to information provided by an industry group, there are also some developments in LED substitutes for small-scale applications, such as water bottle disinfection in homes and offices.

Concerning sourcing a direct substitute to the use of mercury in non-fluorescent low-pressure discharge lamps, alternative substances to mercury are not currently available (Gensch, et al., 2016). Recent information provided by an industry group states that it is still the case that mercury cannot be substituted in low-pressure discharge lamps without fluorescent powder.

Technical feasibility of mercury-free alternatives

A number of projects and studies are currently engaged in the development and application of UVC LEDs (Advanced-UV, 2019; University of Cambridge, 2019). The use cases for non-fluorescent low-pressure discharge lamps are highly specialised, requiring that alternatives can produce light in a specific range of the UVC spectrum. The germicidal range, which is important for the disinfection role of UVCs, is largely considered to be 200 nm – 300 nm (Lux Review, 2017). The spectral range of UVC LEDs varies depending on the source. Lux Review (2017) suggests that UVC LEDs have a wavelength of 200 nm – 280 nm and therefore appropriate for disinfection applications.

UVC LEDs offer a long-life alternative to mercury lamps (Lux Review, 2017). An industry group stated that UV LEDs are a new field of research and development, and that certain applications of UV LED solutions are becoming available, including UVC LEDs, emitting in the critical range for germicidal applications. However, in disinfection applications, there are no retrofit solutions realistically possible, as UVC LED solutions require new equipment.

Information provided by an industry group also states that the current efficiency of UVC LED technology is considerably lower (4% relative to 30% in UVC lamps), and that it is likely to be a minimum of five years before conventional lamps are no longer needed in new equipment.

Economic feasibility of non-mercury alternatives

The upfront costs associated with UVC LEDs is higher than for UVC mercury lamps (€10 per unit for LEDs vs. €5 per unit in the case of UVC lamps in residential water purification process (Lighting Europe, 2015b)). Additionally, as previously mentioned, energy efficiency is lower in UVC LEDs.

According to information provided by an industry group, there are however no UVC LED retrofit lamps available for current installations.

An industry group also stated that UV-emitting units bear significant running costs relative to UV LED lamps. For example, UV lamps cost approximately $0.5 per Watt, whilst UVC LEDs cost approximately $400-500 per Watt. In large water purification systems in cities, systems can exceed 100 kW, resulting in significant costs under UVC LED application.

Health/Environmental Risks and benefits of non-mercury alternatives

UVC LEDs are mercury-free and have lower energy consumption than UVC lamps. However, due to the lower wall plug efficiency of current LED alternatives, they would report higher levels of energy consumption than mercury UVCs (Gensch, et al., 2016).

Also, although UVC LEDs are mercury-free, there are some concerns over end-of-life management, due to the presence of potentially hazardous materials (Seong-Rim, et al., 2011).

Examples of regional or national restrictions

In Europe, Directive 2011/65/EC (Restriction of Hazardous Substances (RoHS) Directive) governs the use of mercury in non-fluorescent low-pressure discharge lamps and associated alternatives. Under Article 4(1) of the RoHS Directive, Member States must ensure that electrical and electronic equipment does not contain mercury. Annex III outlines exemptions from Article 4(1), which includes a ≤ 15 mg limit on the mercury content of low-pressure discharge lamps (4(a)) (Gensch, et al., 2016).

Error! Reference source not found. provides a summary of the disparity between the restrictions applied by EU legislation and the Minamata Convention. Under the Minamata Convention, a limit on the use of mercury in these lamps is not currently in place. In addition, there is no national legislation on the use of mercury in non-fluorescent low-pressure discharge lamps in the US, Canada, China or Australia. However, an industry group stated that India, Thailand, Ukraine and the Eurasian Economic Community (EurAsEC) have implemented national legislation on the use of mercury in non-fluorescent low pressure discharge lamps. Further, Jordan, Turkey, UAE, Saudi Arabia, Vietnam and South Korea have adopted national legislation in line with the RoHS Directive. In addition, the Gulf regions and Brazil are preparing national legislation.

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Eye makeup, cleansing products and mascara containing thiomersal

Summary overview

Thiomersal is an organic compound, containing ethyl mercury, which is often used as a preservative in mascara, eye makeup and cleansing products (WHO, 2011). Thiomersal provides a useful role, extending the shelf life of cosmetics and limiting the risk of infection to cosmetic users. However, due to the risk of allergic reaction and the wider health impacts associated with exposure to mercury, the concentration of mercury in eye makeup products is restricted by legislation internationally.

Currently, under Article 4(1) of the Minamata Convention, countries are prohibited from manufacturing, importing and exporting cosmetics containing more than 1 ppm of mercury, from 2020. However, Part 1 of Annex A specifies that eye makeup products using mercury as a preservative, where ‘no effective and safe substitute preservatives are available’ are exempt from Article 4(1).

There are a number of mercury-free alternatives available as a preservative including parabens, organic acids and dermosoft multifunctionals. Therefore, there is scope for the adoption of mercury-free alternatives for use in eye makeup, cleansing products and mascara. The technical feasibility of these alternatives relies on a number of factors, such as the purpose of the product and interaction of the alternative with other ingredients in the product. With the exception of organic acids, the mercury-free alternatives can however also be linked to detrimental health effects.

Thiomersal is no longer in use by the European cosmetics industry, however few alternatives are considered to have the same level of efficacy as thiomersal.

Globally, the cosmetics industry was valued at $532.4 billion in 2017, with eye makeup products comprising a significant proportion of this value (Orbis Research, 2018). The cosmetic preservative market is expected to exceed $1.4 billion in revenue by 2024, with greater consumer consciousness driving change in the market (Global Market Insights, 2018).

Technical Description

The majority of purchased cosmetic products are stored at room temperature in households, in relatively moist conditions. These conditions, combined with repeated, regular use by consumers, leave cosmetic products susceptible to microorganism growth (ICCR, 2016). For eye makeup products, which have a high water content, such as mascara and liquid eyeliner, preservatives are required to limit microbial growth and extend the shelf life of these products.

Thiomersal is a key preservative used in eye makeup products, to prevent fungal and bacterial growth and limit the risk of infection for consumers. Although thiomersal serves reduces the spread of microorganisms, mercury compounds can cause skin irritation, neurotoxicity and kidney damage (EWG, 2019a). The North American Contact Dermatitis Group reported thiomersal as the fifth most common allergen, with 11% of patch-test patients experiencing allergic reactions, despite its low clinical relevance (Fonacier & Boguniewicz, 2016). In spite of these concerns, WHO scientist, Tempowski, states that ‘the risk-benefit analysis favours the use of these preservatives’, due to their ability to inhibit bacterial and fungal growth (Scientific American, 2013).

Range of mercury content/consumption per unit product

Mercury concentrations in eye makeup products vary depending on the product yet usually do not exceed 1 ppm. According to information provided by an industry group, thiomersal is no longer used by the European cosmetics industry, based on knowledge of the 2016 Cosmetics Europe Preservative Use Survey for the preservation of cosmetic products. This Survey was completed by 85 organisations in the sector, including multinational organisations and SMEs. In addition, over 60,000 product types were analyses, accounting for over 60,000 product formulations.

Availability of non-mercury alternatives

Main alternatives: Parabens, organic alternatives

COWI (2008) suggests that, for the use of mercury as a preservative in cosmetics, 'alternatives dominate the market, but new products with mercury also have significant market share'. Therefore, there is scope for the adoption of mercury-free alternatives.

Phenoxyethanol, methylisothiazolinone and parabens are mercury-free substitutes used to replace thiomersal in eye makeup products. However, these alternatives are also associated with detrimental health impacts, from allergic reactions to toxicity (Scientific American, 2013). Organic preservatives, such as benzoic acid and sorbic acid, as well as organic ingredients, such as honey and sea salt, are also used by some cosmetic companies. Dermosoft multifunctionals, which combine organic acids and chemical compounds, can also offer an alternative to thiomersal, effectively tackling microbial growth through combining multiple preservatives (Thiemann & Jänichen, 2014).

Some companies also choose to use sterilisation as an alternative to preservatives, using the Ultra-High-Temperature process (UHT) to heat and sterilise the product, before quickly cooling it. In addition, as high water content is one of the key causes of microbial growth, some brands are innovating to replace water with a gelled substitute, removing the need for preservatives altogether (EcoMundo, 2019).

Therefore, there are a number of mercury-free alternatives available, and according to the Environmental Working Group's (EWG) Skip Deep Cosmetics Database, there are no eye makeup products currently available in the US that contain thiomersal (EWG, 2019b). This suggests that there is scope to replace the use of thiomersal in cosmetic products.

Technical feasibility of mercury-free alternatives

Several factors are considered when selecting the most suitable preservative to use in cosmetic products. This decision is linked to the expected performance of the product, consumer behaviour and the specific requirements of the product (ICCR, 2016). Alongside these key factors, preservatives must be determined as safe, and aim to use the minimum concentration of preservatives required to ensure the product does not spoil. A consideration of the interaction between preservatives and other product ingredients is essential, to ensure the preservative operates effectively. Therefore, the technical feasibility of alternatives is product-specific, as it depends on the interaction of substitute preservatives with other product ingredients.

Organic preservatives, such as sorbic or benzoic acid, are effective against most fungi. However, they tend not to be particularly effective against bacterial growth (Microchem Laboratory, 2018). Multiple organic preservatives can be combined to achieve wider success in limiting microbial growth. However, these alternatives also precipitate in products with high water content, which diminishes their effectiveness (ibid). Phenoxyethanol is particularly stable and not pH dependent, unlike some organic preservatives, which require a pH range of 2-6. Parabens are most widely used, in both rinse-off products and makeup products used throughout the day, providing a suitable alternative to thiomersal (ibid). It can also be useful to combine preservatives, as is the case with dermosoft multifunctionals, to achieve a more cohesive antimicrobial effect (Thiemann & Jänichen, 2014). Therefore, there are a number of technically feasible alternatives that are already commercially available. However, it is important to also consider practical and health-related factors, to ensure the preservative is suitable for the product.

Economic feasibility of non-mercury alternatives

The cost of non-mercury alternatives varies depending on the preservative. The cost of cosmetic ingredients is an important consideration, as it greatly influences the marketing of products. Although consumers are moving towards more affordable cosmetics, the cost of antimicrobials is not necessarily negative, as consumers are generally willing to pay to avoid negative health outcomes (Halla, et al., 2018).

Health/Environmental risks and benefits of non-mercury alternatives

The health and environmental risks associated with non-mercury alternatives vary depending on the substitute. Parabens are often used in cleansing products. However, these preservatives are linked to a number of health concerns, including damage to skin cells, reproductive toxicity and endocrine disruption. Phenoxyethanol is also used as a preservative in cosmetic products, yet it has been linked to allergic reactions, including eczema and anaphylaxis. However, it is a viable alternative, if individuals are not allergic to the preservative. Methylisothiazolinone is another preservative used in mascara and cleansing products. However, it is linked to inhalation toxicity and allergic reactions (Breast Cancer Prevention Partners, 2019). In 2015, 75 000 metric tonnes of preservatives were used in cosmetic products globally. Therefore, organic alternatives, such as honey and sea salt, which naturally break down without causing harm to the environment, are preferable (LUSH, 2019).

Examples of regional or national restrictions

In Europe, Regulation (EC) 1223/2009 is the primary piece of legislation governing the use of mercury in eye makeup, cleansing products and mascara. Under Article 14(1)(a), restrictions are placed on the use of certain substances in cosmetic products, listed under Annex II. Mercury and its compounds are banned, with the exception of special cases outlined in Annex V. The use of thiomersal in eye makeup products is one of the special cases identified by the Regulation, where a maximum concentration of 0,007 % of mercury is permitted in eye makeup, mascara and cleansing products. If thiomersal is combined with other mercury compounds permitted under Regulation (EC) 1223/2009, the maximum concentration of mercury in eye products remains the same (i.e. 0,007 %). Phenylmercuric salts (including borate) found in eye products are also subject to the same maximum concentration. In addition, through the introduction of a ‘date of minimum durability’ or a ‘period after opening’ date in Europe, consumers are more aware of the appropriate shelf life of cosmetic products (Cosmetics Europe, 2019).

Under Article 4(1) of the Minamata Convention, countries are prohibited from the manufacture, import and export of cosmetics, other than eye-area cosmetics (where mercury is used as a preservative and no effective and safe substitute preservatives are available), containing more than 1 ppm of mercury, from 2020. Eye makeup products are however exempt from restrictions, where no substitute preservatives are available, as ‘the intention is not to cover cosmetics, soaps or creams with trace contaminants of mercury’ (UNEP, 2013).

In the US, the Food and Drug Administration (FDA) leads on legislative development for cosmetics. The concentration of mercury compounds in eye makeup products is limited to 0,0065 %, and is only permitted in the case that no mercury-free alternatives are available (US FDA, 2017). All other cosmetic products must have a mercury concentration of less than 1 mg per kg. The FDA declares that products should not be sterile; however, the concentration of non-pathogenic organisms should be low (Halla, et al., 2018).

The ASEAN Cosmetic Directive reflects EU legislation, with thiomersal permitted as a preservative in eye makeup and cleansing products, as long as the concentration of mercury does not exceed 0,007 %. The maximum concentration of mercury remains 0,007 % if other mercury compounds are contained in the product (Health Sciences Authority, 2018). All 10 Member States[3] were required to implement the Directive by January 2008.

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Melt pressure transducers, transmitters and sensors using a capillary system

Summary overview

Melt pressure transducers, transmitters and sensors are used to control and measure melt pressure during extrusion, a process used to create objects of a fixed cross-sectional profile. Transducers maintain dimensional stability, to ensure that the products being extruded align to specific design requirements (Dynisco, 2016). They are used in processes for food and beverage packaging, piping, medical product manufacturing and recycling.

Melt pressure products entered the market in the 1950s, initially protected by a patent, which influenced their supply and market prices. Only recently have melt pressure transducers become more openly available on the market, produced by multiple manufacturers (Bagsik, 2019). However, industry data suggests that only 50% of extruders are fitted with melt pressure measuring equipment (Dynisco, 2016).

Currently, melt pressure products are not covered by the Minamata Convention.

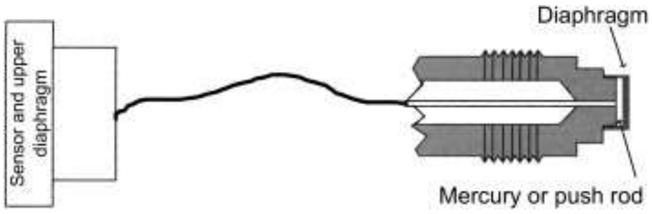
Sodium-potassium alloy and silicon oil are technically-viable alternatives to mercury, which are available internationally. Although neither of these substances operate with the same effect under high temperatures, silicon oil offers a suitable alternative to mercury in food, medical and pharmaceutical applications. Sodium-potassium alloy (NaK) offers a suitable alternative to mercury in plastics manufacturing. These alternatives are already commercially available, with mercury-free transducers manufactured in and exported from Europe, Asia and North America. They also have limited impact on health and the environment relative to mercury. The EU is the only jurisdiction to implement a limit on mercury content in melt pressure transducers (0,1 %). In the US, under the Federal Food, Drug, and Cosmetic Act, substances must be deemed Generally Regarded as Safe (GRAS) if they are used for specific food, medical or pharmaceutical applications. Mercury-free alternatives, silicon oil and NaK are GRAS.

Technical Description

Melt pressure transducers, transmitters and sensors enable accurate pressure measurements to be made, enhancing product quality and limiting damage to equipment (Dynisco, 2016). In melt pressure transducers, pressure transmission occurs in a closed capillary system filled with a transmission medium (i.e. mercury). The system is designed to transfer the pressure exerted on the diaphragm, pictured in Figure 8, to the transduction feature (i.e. upper diaphragm with the strain gauge). The strain gauge then converts the physical pressure into an electric signal (Gefran, 2017). In cases of excess pressure during extrusion, this process enables transducers to ensure safety, by switching off extruder driving systems when defined pressure limits have been exceeded (Bagsik, 2019).

In melt pressure transducers, mercury was traditionally used as the transmission medium, due to its capacity to transmit pressure readings at high temperatures. However, there is potential risk of mercury leakage during the manufacturing process.The EU through Directive 2011/65/EC (RoHS Directive) has required the use of inert mercury-free alternatives, such as silicon oil and sodium potassium alloy (NaK) (Industry Search, 2019). Despite the absence of regulation in other countries, many countries outside the EU also manufacture mercury-free alternatives, appealing to international customers.

Figure 8 – Melt pressure transducer cross-section (Wagner, et al., 2014)



Range of mercury content/consumption per unit product

The mercury content in melt pressure transducers varies depending on the model. Dynisco states that their pressure transducer 420/460 model contains 7mm^3 of mercury as the transmission medium. However, models released by other companies display a mercury filling volume of 30mm^3 – 40mm^3 (Gefran, 2014). In addition, Dynisco have provided another estimate of the mercury fill being approximately 0.003 cubic inches per transducer (~50mm^3) (Dynisco, 2016).

Availability of non-mercury alternatives

Main alternatives: sodium-potassium alloy, silicon oil

Although mercury devices are still on the market, a number of alternative transmission mediums exist. It is essential that alternatives meet certain requirements to ensure that they are suitable for extrusion processes. For example, products must be capable of withstanding high temperatures (up to 700°F) and high pressures (up to 30,000 psi), as well as being able to function in potentially corrosive settings (Dynisco, 2016). In addition, it is essential that the substances replacing mercury are capable of transferring pressure in a similar fashion.

The two key alternatives to the use of mercury as a transmission medium are silicon oil and sodium-potassium alloy (NaK). The latter is capable of transferring pressure with comparable quality to mercury (Gräff, 2015). However, Gräff (2015) states that silicon oil is not always an appropriate alternative to mercury, due to the disparity in its capacity to transfer pressure in a comparable manner to mercury. However, the silicon oil substitute is commonly used in food and medical applications, where lower temperatures are required.

Some companies have also developed sensors which do not require a transmission fluid. Instead, pressure is transferred to a silicon element through a diaphragm (Gefran, 2017).

Technical feasibility of mercury-free alternatives

Mercury-free alternatives are technically feasible and already commercially available. Through the use of advanced production processes, melt pressure products can be produced without the mercury filling and still provide an accurate reading (Müller, 2019). Sodium-potassium alloy is an alternative used by multiple manufacturers, due to its ability to mimic the characteristics of mercury. Sodium-potassium alloy alternatives can withstand temperatures of 400°C and according to Gräff (2015, p. 4), their mercury-free alterative is '100% market-compatible with all common manufacturers'. Due to its capacity to function under high temperatures, NaK is an ideal alternative for the plastics manufacturing industry (Industry Search, 2019).

In addition, the majority of manufacturers also produce melt pressure transducers which use silicon oil as an alternative transmission medium. Although these products have limits on the temperature which they can withstand, their use is ideal in food, medical and pharmaceutical applications.

Economic feasibility of non-mercury alternatives

Due to increasing pressure from the US Food and Drug Administration (FDA) and the EU Restriction of Hazardous Substances (RoHS) Directive, several manufacturers already produce mercury-free alternatives (Gräff, 2015). As these alternatives are readily available on the market, manufacturers will not face the additional cost of having to invest in research and development to create mercury-free alternatives (Gefran, 2010). All European manufacturers comply with the RoHS Directive and manufacturers based in China already produce mercury-free alternatives.

Health/Environmental Risks and benefits of non-mercury alternatives

The primary risk of mercury transducers, transmitters and sensors is the exposure to mercury during manufacturing processes. In addition, the use of mercury is particularly concerning in processes concerning food packaging, due to the direct link to human consumption (Dynisco, 2016). The silicon oil and NaK alternatives are considered safe by the US FDA, with neither of these alternatives containing hazardous substances. However, NaK is known to react strongly with water to produce highly-flammable hydrogen. NaK also reacts with CO_2 to produce methane

(Chemwatch, 2009). However, the significance of this reactivity depends on the volume of NaK present. With the relatively low volume of transmission medium fill (7mm^3-50mm^3) for melt pressure transducers, the effect is likely to be minimal.

Examples of regional or national restrictions

In Europe, the RoHS Directive is the only regulation which governs the use of mercury in melt pressure transducers, transmitters and sensors. Although transducers using mercury are still available in the EU, all EU manufacturers fully comply with the RoHS.

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Devices using mercury to measure volume change of part of a body (strain gauge to be used with plethysmographs)

Summary Overview

Mercury is used in strain gauge plethysmography to measure blood flow and blood pressure. This is used to diagnose arteriosclerosis, a disease affecting arterial walls and resulting in reduced blood circulation.

Mercury usage in plethysmography is low in comparison to some other medical applications such as sphygmomanometers. Mercury-containing strain gauges are now rare. It is estimated that, for example, in Sweden only 200 strain gauges are used per year, and one major global producer of strain gauges consumed 946 grams of mercury in 2004 (ECHA, 2011). It is estimated that 0.014 t Hg was placed on the EU market in 2010.

Currently, strain gauges along with other measuring devices have been exempted from Annex A of the Minamata Convention in the absence of a feasible mercury-free alternative.

It is now the case that feasible mercury-free alternatives are available for all applications of strain gauges with the exception of certain research applications where reference gathered over decades using mercury-containing strain gauges is relied upon. The most prominent alternative is indium-gallium strain gauges, which are compatible with expensive wider electrical equipment that mercury strain gauges function with.

Technical Description

The mercury strain gauge consists of a fine rubber tube filled with mercury which is placed around the body in the area where blood pressure is to be measured.

Range of mercury content/ consumption per unit product

1.25g elemental mercury per strain gauge (ECHA, 2011).

Availability of non-mercury alternatives

Main alternatives: Strain gauges with indium-gallium, photo cell/laser-Doppler techniques

There are technically and economically feasible mercury-free alternatives available (ECHA, 2011). Indium-gallium strain gauges are the main alternative to mercury strain gauges.

Photo cell and Doppler techniques are typically used for measurements in fingers and toes, for which indium-gallium gauges are not suitable (COWI, 2008). The photo cell technique registers changes in tissue colour at different pressures. The Doppler technique measures the velocity of red blood cells to determine blood flow. Ultrasonic devices are used for larger applications, and laser devices are used for measuring smaller volumes.

The world leading manufacturer is D.E. Hokanson, Inc., in the USA where both mercury and indium-gallium strain gauges are produced for export (COWI & ICF, 2017). No mercury strain gauges have been sold in Europe since 2014 and according to NEWMOA, mercury-filled strain gauges are rarely used (NEWMOA, 2016).

Technical feasibility of mercury-free alternatives

According to COWI (2008) photo cell and laser-Doppler technique or gallium/indium strain gauges are capable of identifying a variety of diagnosis offered by mercury-containing equipment. Indium-gallium strain gauges can be used with existing plethysmographs for the same application as mercury strain gauges (ECHA, 2011).

In the area of research however, there is no alternative to mercury-containing plethysmographs where absolute blood flow in arms and legs is measured. This is due to the body of research and reference materials built up over decades of use. Indium-gallium gauges have a higher freezing point and lower resistance and so cannot be used for some applications, specifically Raynaud's disease or small digit tests, or cold water immersion studies (Hokanson, 2019) (COWI & ICF, 2017).

Economic feasibility of non-mercury alternatives

The driving factor for ongoing use of mercury-containing strain gauges is economic as mercury-containing tubes are inexpensive. However they are designed to work with complex electronic equipment costing in excess of EUR 20,000 and with life spans of 10-15 years. As such, clinics are hesitant to replace the complete system other than in the case of technical failure (COWI, 2008). It is possible to retrofit indium-gallium gauges with Hokanson plethysmographs with a few exceptions (COWI & ICF, 2017).

The prices of indium-gallium strain gauges are approximately 40% higher than mercury gauges according to a major supplier (COWI & ICF, 2017). However, ECHA (2011) judged that indium-gallium gauges are economically feasible and estimated the cost of compliance in the EU for restrictions on mercury-containing strain gauges at EUR 2.6 million in the period of 2015-2034. A major producer of mercury strain gauge claimed that indium-gallium is also more difficult to handle during production, requiring more assembly time.

Health/Environmental Risks and benefits of non-mercury alternatives

Gallium is reported to cause skin, eye and respiratory irritation and may cause bone marrow abnormalities with damage to blood forming tissues (ECHA, 2011). There is less information on the toxicological properties of indium. However, due to the clear evidence on the hazardous properties and risk of mercury the usage of indium-gallium strain agues is considered to reduce overall risk to environment and health.

Examples of regional or national restrictions

The export, import and manufacturing of mercury-containing strain gauges to be used with plethysmographs is prohibited in the EU from 31 December 2020 by Regulation (EU) 2017/852 on Mercury.

There are some exemptions to the restriction, notably:

- Non-electronic measuring devices installed in large-scale equipment or those used for high precision measurement where no suitable mercury-free alternative is available;
- Measuring devices more than 50 years old on 3 October 2007
- Measuring devices which are to be displayed in public exhibitions for cultural and historical purposes

Strain gauges to be used with plethysmographs intended for industrial and professional uses were restricted from being placed on the market from 10 April 2014. The restriction also applies to devices which are placed on the market empty if intended to be filled with mercury.

In the USA, mercury strain-gauges are prohibited from sale in the states of Maine, Louisiana, Connecticut and Rhode Island.

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Mercury Vacuum Pump

Summary Overview

A vacuum pump is a device that removes gas from a sealed space to produce a partial vacuum.

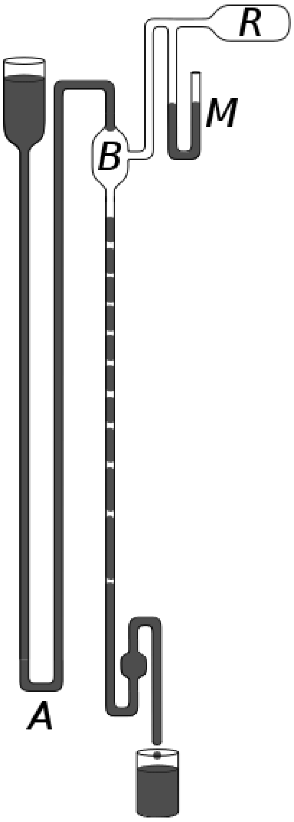
It was reported in 2008 that mercury vacuum pumps were still in operation but not sold (COWI, 2008).

Mercury-free alternatives exist and are widely in use. Positive displacement pumps are used to create low vacuums and momentum transfer pumps are used to create high vacuums (Atta & Hablanian, 1991).

Technical Description

The Sprengel pump is a form of vacuum pump that uses drops of mercury falling through a small-bore capillary tube in order to trap air. Mercury is contained in the reservoir and flows into bulb B, where it forms drops which fall leaving air entrapped in bulb B. Mercury is collected and restored to the left reservoir. In this way almost all air can be removed from bulb B and by extension vessel R.

Figure 9 – Mercury-containing vacuum pump (Beach & Chandler, 1914)



Range of mercury content/ consumption per unit product

3.4 kg mercury (COWI, 2008).

Availability of non-mercury alternatives

Main alternatives: Positive displacement pumps, momentum transfer pump

Positive displacement pumps use a mechanism to expand a cavity, causing gases to flow in from the chamber that is to be extracted, after which the chamber is sealed and gases are exhausted. This can be repeated indefinitely to create an increasing vacuum. Momentum transfer pumps (molecular pumps) use dense fluid or high speed blades to knock gas molecules out of the chamber.

Technical feasibility of mercury-free alternatives

There are technically feasible alternatives to mercury pumps available and widely used.

Positive displacement pumps are most effective for the creation of low vacuums, while momentum transfer pumps are used to create high vacuums.

The KALPUREX process for removing helium from exhaust gases in a planned fusion demonstration power plant (DEMO, potential successor of the ITER) employs two mercury vacuum pumps. Mercury is used as a working fluid because of its very good compatibility with radioactive tritium (Giegerich & Day, 2014). The concept was chosen as the most suitable option on the basis of a Strength, Weakness, Opportunity and Threat (SWOT) analysis (Giegerich & Day, 2014).

Economic feasibility of non-mercury alternatives

There are economically feasible alternatives to mercury using vacuum pumps, evidenced by the fact that no mercury using pumps were sold in the EU since before 2008 (COWI, 2008).

Health/Environmental Risks and benefits of non-mercury alternatives

There are no known environmental downsides to mercury free alternatives to mercury containing vacuum pumps (COWI, 2008).

Examples of regional or national restrictions

According to Directive 2011/65/EU, the RoHS Directive, Member States must ensure that all electrical and electronic equipment placed on the market shall not contain mercury beyond a maximum concentration of 0.1% by weight in homogenous material. There are however exemptions for medical devices and monitoring and control instruments, as well as research applications.

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Tensiometer

Summary Overview

Tensiometers measure the surface tension of liquids and are used in applications such as the determination of soil moisture tension, or for measuring tension in wire, fibres and beams (Committee for Risk Assessment and Committee for Socio-economic Analysis, 2011).

Mercury containing tensiometers are used for measuring the negative pressure of soil water (soil water potential). The potentially mercury-containing component of a tensiometer is a manometer, which is an instrument for measuring pressure.

In the Minamata Convention, there is no reference to tensiometers among measuring devices listed in Annex A.

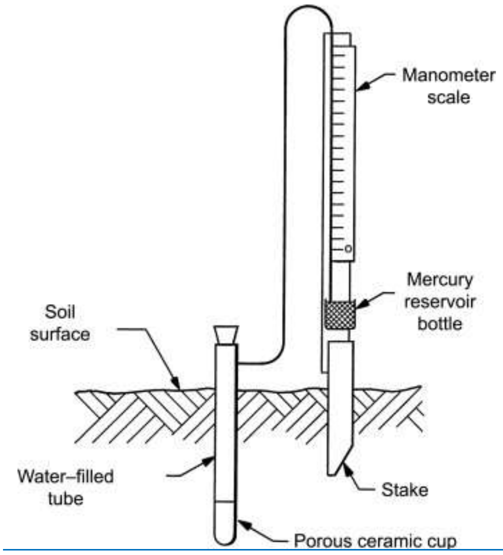
Alternatives exist for mercury containing tensiometers for all applications, and there are no significant health risks or technical feasibility restrictions associated with them. Mercury-free alternatives are usually cheaper than mercury manometers, with the exception of electronic manometers which are significantly more expensive, however provide additional functionality (Committee for Risk Assessment and Committee for Socio-economic Analysis, 2011).

Technical Description

The mercury containing component of a tensiometer is a manometer. Manometers consist of a U-shaped glass or plastic tube that contains a liquid (water, alcohol or mercury) such that the surface of liquid in one end of the U moves proportionately with the liquid in the other end. When pressure is applied, the liquid level in one arm rises and the other drops, enabling a reading to be taken.

A mercury tensiometer contains a capillary tubing linked to the mercury manometer. The capillary tubing is attached to porous cups which are inserted into the soil. Mercury manometers/tensiometers are shipped without mercury and filled with mercury by the user (Committee for Risk Assessment and Committee for Socio-economic Analysis, 2011). There may also be risk of release from breakage, but the highest risk of release is in the waste phase.

Figure 10 – Mercury tensiometer (Kirkham, 2005)



Range of mercury content/ consumption per unit product

70-140 g mercury per manometer.

There was roughly 4 t of mercury estimated to have been accumulated in manometers in the EU in 2011, and 0.04-0.4 t Hg per year placed on the market (ECHA, 2010).

Availability of non-mercury alternatives

Main alternatives: Liquid filled in tube manometers, mechanical alternatives/elastic pressure sensors, electric manometers, other devices

The mercury manometers used in tensiometers are usually replaced by elastic pressure sensors or electric manometers.

Elastic pressure sensors contain elements that are deformed or stretched when pressure is applied to them. The level of displacement is recorded. Common elastic pressure sensors include Bourdon tube manometers and pressure gauges with diaphragms. Bourdon tube manometers use a C-shape tube sealed at one end. Pressure is applied at the open end, causing pressure to be transferred to a gear and indicating needle. Pressure gauges with diaphragms can be mechanical or electric and contain a flexible two-sided membrane, with one side enclosed in a capsule containing a fluid such as air at a known pressure. Pressure is applied to the other side and the bending in the membrane is recorded.

Electric manometers use pressure transducers connected to an analogue to digital converter to transform the sensor response to an electrical signal.

Liquid filled tube manometers can contain liquids other than mercury e.g. water or alcohol.

There are also alternative methods to manometers to measure soil moisture. The gravimetric method determines the water content of soil by weighing it, drying it and measuring the difference in weight.

Technical feasibility of mercury-free alternatives

According to a European producer of mercury manometers, there was no application where mercury manometers cannot be replaced by other devices (Committee for Risk Assessment and Committee for Socio-economic Analysis, 2011).

Bourdon tube manometers are more robust than mercury manometers and suitable for measuring higher pressures (Committee for Risk Assessment and Committee for Socio-economic Analysis, 2011).

Pressure gauges with diaphragm are equally accurate as traditional mercury manometers.

Electronic manometers are widely used and have advantages compared to mercury manometers such as requiring less maintenance and less expertise to use.

The gravimetric method is time consuming and labour-intensive, however is accurate and low-cost.

Economic feasibility of non-mercury alternatives

Alternatives to mercury manometers are usually cheaper (Committee for Risk Assessment and Committee for Socio-economic Analysis, 2011). Mercury manometers costed around €108 in 2006. Prices for bourdon tube manometers ranged from €54 to €122, and prices for pressure gauges with diaphragms ranged from €30 to €76.

Electric manometers were the exception to this, costing 3-4 times more than mercury manometers for similar pressure ranges (Committee for Risk Assessment and Committee for Socio-economic Analysis, 2011).

Health/Environmental Risks and benefits of non-mercury alternatives

Mercury manometers/tensiometers are shipped without mercury and filled with mercury by the user (Committee for Risk Assessment and Committee for Socio-economic Analysis, 2011). There may also be risk of release from breakage, but the highest risk of release is in the waste phase.

There is no risk associated with the use of alternative liquids in manometers and the risks associated with electronic alternatives are not significant (Committee for Risk Assessment and Committee for Socio-economic Analysis, 2011).

Examples of regional or national restrictions

In Europe, tensiometers containing mercury intended for industrial and professional uses have been prohibited from being placed on the market from April 2014 according to the Regulation 1907/2007 on the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH). This restriction also applies to tensiometers supplied to the market empty with the intention of being filled with mercury. Electronic manometers also fall under restriction of the RoHS Directive which prohibits maximum mercury concentration over 0.1% in electrical and electronic equipment placed on the market.

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Production of Vinyl Chloride Monomer (VCM)

Summary Overview

Mercury catalysts are in large-scale commercial use in the production of vinyl chloride monomer (VCM) primarily in China (DCM Shriram, 2019), but also in India (ICIS, 2005) and Russia (UNEP, 2017). The acetylene process is used in the EU by Fortischem AS (formerly Novacke Chemicke Zavody AS) in the Slovak Republic, in parallel to the ethylene process. It is used for approximately 25% of the total VCM production. Approximately 20 t of catalyst containing 10% by weight of mercury chloride (2 t) is consumed annually in this plant. Under Annex III of Regulation (EU) 2017/852 on mercury, this manufacturing process will be phased out by 1 January 2022.

VCM is an industrial chemical mainly used in the production of polymer polyvinyl chloride (PVC). 35 million tonnes of PVC are used globally per annum as a building material and in household products (IPEN, 2015). Asia represents half of global production capacity and half of the global market for PVC, with latest estimates being 14 million tonnes produced in China considering only the mercury-using process (UNEP, 2017). VCM is produced without mercury in most countries using ethylene as the feedstock for the chemical process. A mercury catalyst is utilised only when acetylene is used, which is derived from coal, and as such is still prevalent in VCM production in China where coal is an abundant resource (IPEN, 2015). Global mercury consumption for VCM production was 1210-1240 tonnes in 2015 (UNEP, 2017). China's VCM mercury consumption is the principal reason for continued mercury production from primary mercury mining in China, since it consumes the majority of China's mercury supply (The GEF 2018).

Currently, the Minamata Convention restricts mercury use in vinyl chloride monomer production and prohibits its use five years from the date of a mercury-free catalyst being available, and also commits plants to reduce mercury per unit production by 50% in 2020 compared to 2010 levels. The Convention also requires measures to reduce reliance on mercury from primary mining.

It is currently not fully understood the extent to which mercury is released from the production process, and there are concerns as to the management of mercury waste streams such as the spent catalyst and activated carbon filters, which capture 60% of mercury consumed in production. It is currently estimated that 30% of mercury used is lost in the process through unknown pathways. The 2015 inventory of mercury use included for the first time an estimate of emissions to air from VCM production at 58 tonnes globally (UNEP, 2018).

It is estimated that 520 tonnes of mercury were retrieved from recycling VCM catalysts in China in 2014 and estimates have been as high as 650 tonnes for 2015 figures (UNEP, 2017). According to Lin et al. (2016), China is phasing out usage of a high mercury catalyst, and replacing it with 50% lower mercury catalysts.

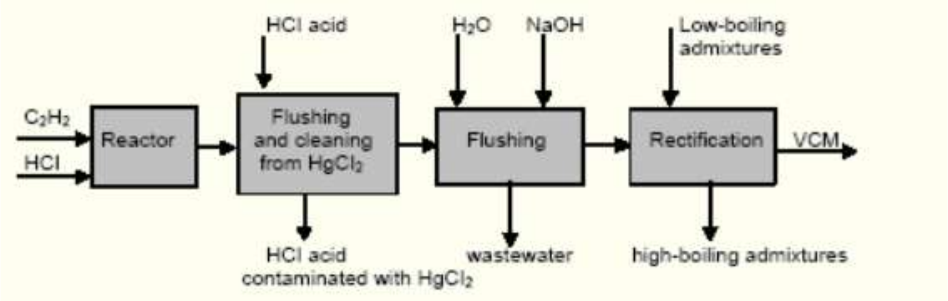
The main mercury-free alternative is to use the petroleum/natural-gas derived ethylene method of production instead of coal-derived acetylene. Research and testing are underway to find an economically feasible alternative using the acetylene method. Russia and India are comparatively estimated to consume 10-15 tonnes of mercury for VCM production.

Technical Description

VCM is the basis chemical for the production of polyvinyl chloride, an important polymer. Two synthesis routes are used in an industrial scale. One is based on ethylene (produced from natural gas or crude oil as feedstock) and is now dominant in the world. The acetylene route was historically more important, but has been phased-out in most countries due to economic reasons.

In this process coal-derived coke is heated with caustic soda to produce calcium carbide, which is then hydrolysed to create acetylene. Acetylene is then reacted with hydrogen chloride using mercury (II) chloride ($HgCl_2$) as a catalyst to produce vinyl chloride, which is then polymerized to create PVC. The catalyst is used with activated carbon as a support. When the support is installed, it contains between 8-12% mercury (II) chloride. Over time, the catalyst is depleted and once the content in the support drops below 5%, it will be replaced. However, since 2010 China promotes the use of low-mercury catalyst with an initial mercury content of about 4-5% (GEF 2017).

Figure 11 – Production of VCM using a mercury catalyst (Danish EPA, 2005)



In China the acetylene route and the use of mercury catalyst still plays a significant role in vinyl chloride monomer production. The calcium carbide process of PVC synthesis was largely phased out in the 1960s due to high energy consumption and waste, however in China this method is still pervasive due to the use of coal as a starting material (IPEN, 2015).

Range of mercury content/ consumption per unit product

Historically, the catalyst is 8-12% mercuric chloride. The low mercury version is 4-5% mercury.

There were 14 million tonnes of VCM produced via the carbide process in China in 2014, and a mercury consumption of 1,216 tonnes (UNEP, 2017). Therefore, mercury use is estimated at 0.087 kg Hg per tonne of VCM.

In China the grams of mercury per ton of VCM produced ranges from 97 g Hg/t VCM to 49 g/t as a result of the shift to a lower mercury catalyst (Lin et al., 2016).

Availability of non-mercury alternatives

Main alternatives: Use of ethylene instead of acetylene; use alternatives to PVC.

The production of VCM in most countries does not use mercury catalysts, using ethylene as the hydrocarbon feedstock in VCM production rather than acetylene. Ethylene is produced from petroleum or natural gas, while acetylene is produced from coal, which is the primary reason for its continued usage in China which has large coal reserves but must rely on imported petroleum which is subject to price fluctuations. Additionally, PVC plants are often located far from the sea and so use of local coal has been preferred to transporting ethylene long distances by land.

Technical feasibility of mercury-free alternatives

As previously mentioned, it is possible to produce VCM from ethylene rather than acetylene using petroleum and gas as a feedstock. In China due to an abundance of coal resources and no natural gas it is likely that usage of acetylene will continue, especially in inland regions far from sea ports. There is ongoing research into production of VCM using acetylene using alternative catalysts, most notably gold catalysts, which have been demonstrated to have comparable catalytic efficiency to commercial mercury catalysts (Chai et al., 2019). Other alternative catalysts include nitrogen-doped activated carbon and ruthenium (Shen et al., 2018) (Li et al., 2018).

Economic feasibility of non-mercury alternatives

Most VCM production around the world uses ethylene as a feedstock derived from natural gas which does not make use of a mercury catalyst. This process is less energy-intensive than the mercury catalyst using acetylene process. According to an industry expert, there are economic costs related to the transportation and storage of ethylene as it is a liquid.There are also differences in investment costs of technical process equipment, with costs being higher for etyhelene.

Usage of mercury-free alternative catalysts in the acetylene process are potentially limited by economic performance, most notably gold catalysts. The GEF funded project, noted below, will be examining the economic feasibility of mercury free catalysts.

Health/Environmental Risks and benefits of non-mercury alternatives

The fate of mercury lost from the catalyst as it depletes is not well understood. The 2017 UNEP report on global supply, trade and demand of mercury reported that 30-50% of mercury remains in the spent catalyst and is mostly recycled while another 30-50% is caught in activated carbon filters that are also recycled. 4-6% of mercury ends up in waste products, meaning that there is approximately 30% of mercury that is lost in the process with unknown destination (UNEP, 2017).

Global mercury consumption for VCM production was 1210-1240 tonnes in 2015 (UNEP, 2017). 520 tonnes of mercury were retrieved from recycling VCM catalysts in China in 2014 and estimates have been as high as 650 tonnes for 2015 figures (UNEP, 2017). The 2018 Global Mercury Assessment reported for the first time an estimate of emissions to air from VCM production at 58 tonnes in 2015 (UNEP, 2018).

Examples of regional or national restrictions

Mercury use in the production of VCM is prohibited in the EU from the 1 January 2022 according to Regulation (EU) 2017/852 on Mercury (Article 7(1) and Annex III (Part I)).

In China, there were plans to replace all conventional Hg containing catalyst with low Hg containing catalysts by 2015 (50% Hg content compared with the conventional catalyst), with progress still ongoing in 2015 according to the Chinese Chemical Industry Environmental Protection Association (Lin et al., 2016). There is a five year Global Environment Facility (GEF) funded project underway with funding of over €16 million for the reduction and minimization of mercury in PVC production in China (The GEF, 2018).

In Japan, the Regulation on the use of mercury or mercury compounds in products and manufacturing processes prohibits the use of mercury in VCM production (Ministry of the Environment Japan, No date).

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Production of polyurethane

Summary Overview

Polyurethane is a polymer comprised of a series of organic units, which are linked by urethane (ChemEurope, 2019). Polyurethane is available in a number of forms and densities, and is used in bedding, thermal insulation and in floorings (ibid). However, the primary use of mercury catalysts is in the production of polyurethane coatings, adhesives, sealants and elastomers (referred to as CASE applications). According to a major catalyst supplier, elastomers comprise approximately 90% of the mercury catalyst market (Norwegian Climate and Policy Agency, 2010).

Mercury catalysts are used for the manufacture of a number of polyurethane elastomers. In particular, mercury is used in the production of polyurethane elastomers that are cast into complex shapes, or sprayed onto a surface as insulation (i.e. corrosion protection). It is estimated that polyurethane elastomer castings and coatings comprise at least 90% of the total applications of polyurethane elastomers (COWI, 2008).

Under Annex B Part II of the Minamata Convention, a series of measures are outlined, to reduce the use of mercury catalysts and conduct research into the use of mercury-free alternatives. However, there is no prohibition of the use of mercury-containing catalysts in polyurethane production.

It is estimated that globally, mercury catalysts account for less than 5% of polyurethane production and that in 2008, 300-350 tonnes of mercury catalyst were used in the global production of polyurethane elastomers (COWI, 2008).

Bismuth and zinc carboxylates, and tertiary amines, are technically an economically viable alternatives to the use of mercury catalysts, which are already in use internationally. However, both of these alternatives require additional adjustments, to ensure that they reflect the characteristics of mercury. Relative to mercury, these alternatives have limited impact on health and the environment.

Use of mercury compounds in the production of polyurethane is completely prohibited within the EU since 1 January 2018.

Technical Description

In the formation of polyurethane, mercury catalysts are used in the reaction between a polyol and an isocyanate component. During the reaction, mercury catalysts enable a long induction period, followed by a rapid reaction for curing the product. The catalyst tends to be present in the polyol component. The mercury catalyst is integrated into the polymer and remains present in the final polyurethane product (Norwegian Climate and Policy Agency, 2010).

Organic mercury compounds provide the desired characteristics of catalysts for the majority of polyurethane applications. Mercury catalysts offer an initial induction period (pot life) where the reaction between polyurethane and the catalyst is slow or does not occur. This enables sufficient time for the mixture to be cast, following the addition of the catalyst. This provides the manufacturer with greater oversight of the polyurethane application (ibid).

Secondly, mercury catalysts engender a rapid reaction following the initial induction period, which enables the product to reach its final form and adopt the desired properties in relation to shape, density and malleability. In addition to allowing the product to take on its desired characteristics, the rapid reaction enables the production process to occur in a timely manner (COWI, 2008).

Range of mercury content/consumption per unit product

The mercury catalyst is typically added to the polyurethane systems at concentration levels of 0.2 % – 1 %. However, this depends on the specifications of the end product and the other components present (Norwegian Climate and Policy Agency, 2010).

Availability of non-mercury alternatives

Main alternatives: bismuth and zinc carboxylates, tertiary amines, organotin compounds

According to the European trade association for producers of diisocyanates and polyols (ISOPA) and the European Aliphatic Isocyanates Producers Association (ALIPA), using the polyurethane systems currently in place with a non-mercury catalyst does not enable the same level of performance as using these systems with mercury catalysts. Therefore, designing alternative polyurethane systems, which use alternative polyol or isocyanate components, with a non-mercury catalyst is preferable (ISOPA, 2009).

There is also the potential for the development of systems based on other polymers to replace mercury polyurethane systems. However, due to the wide range of applications required, finding suitable polymers is expected to be a complex task (Norwegian Climate and Policy Agency, 2010).

In contrast, non-mercury catalysts are available for the majority of applications, and are used as catalysts in over 95% of polyurethane elastomer applications (ChemEurope, 2019). Several non-mercury catalysts with distinct properties have been developed for polyurethane elastomers, as a ‘one-size-fits-all’ approach is not applicable in the case of replacing mercury catalysts for multiple applications (Norwegian Climate and Policy Agency, 2010).

Bismuth and zinc carboxylates have been used as alternatives to mercury catalysts since the 1980s. Bismuth and zirconium systems are also available on the market as mercury catalyst alternatives. In addition, tertiary amines and organotin compounds have also been used as substitutes to mercury catalysts in a range of applications (ibid).

Technical feasibility of mercury-free alternatives

Bismuth and zinc carboxylates have been adopted for many decades, and are designed to replace the use of mercury, lead and tin catalysts. These catalysts have displayed commercial success, despite their shortcomings relative to mercury (ChemEurope, 2019). For example, bismuth compounds require manufacturers to make adjustments to account for the differing reactivity of bismuth relative to mercury. In addition, bismuth compounds result in greater viscosity relative to mercury, as the reaction occurs. This produces polymers with different consistencies, relative to the polymers which a mercury catalyst produces. However, the use of a bismuth neodecanoate and zinc neodecanoate mixture enables users to adjust the concentration of the two metals, and hence adjust the behaviour of the gel (Norwegian Climate and Policy Agency, 2010).

Bismuth and zirconium systems are also used as mercury catalysts for the production of polyurethane elastomers. However, their sensitivity to moisture renders it difficult for these systems to act as catalysts in the presence of water.

Organotin compounds are not considered direct replacements for mercury catalysts, although they have been used to replace mercury in some applications. For example, organotin compounds are used in polyurethane systems to produce foams, coatings, adhesive and elastomers. However, these compounds cannot replace the use of mercury in all applications (ibid).

Tertiary amines have also been used as catalysts, producing a long pot life, followed by rapid reaction rate, two characteristics necessary for a suitable alternative to mercury catalysts. These can be used in adhesive, sealant and elastomer applications. However, the water content of polyurethane systems needs to be controlled, to ensure that foaming issues do not occur (ibid).

The aforementioned catalysts are all currently available on the market.

Economic feasibility of non-mercury alternatives

The cost of mercury-free catalysts is expected to be comparable with the cost of mercury catalysts. The cost of mercury catalysts has increased, and therefore, the price of alternatives is not expected to be a barrier (COWI, 2008). Broader research and development is expected to engender higher costs, as sourcing substitutes for a relatively simple polyurethane system is expected to require two months of research from one researcher (equivalent to €10,000 - €15,000). However, it is not expected that additional machinery costs will be incurred, as the same machinery can be used for both mercury and non-mercury systems (Norwegian Climate and Policy Agency, 2010).

Only non-mercury alternatives are used for manufacturing of polyurethane in the EU.

Health/Environmental Risks and benefits of non-mercury alternatives

All of the mercury catalyst used in polyurethane production remains in the product. This represents 0.2 to 1% of the polyurethane in products and several hundred tonnes of mercury catalyst globally. In most cases, polyurethane waste is subject to unspecific waste disposal and therefore represents significant risks of emissions and releases to the environment.

There are in some cases health concerns associated with non-mercury alternatives. For example, zinc neodecanoate is reported to cause potential irritation to skin and eyes. In addition, there are some adverse effects associated with ingestion of zinc and bismuth. However, bismuth and zirconium are not considered to be skin irritants (ibid).

One of the primary environmental concerns associated with the use of mercury in polyurethane elastomers is the contamination of municipal waste streams and waste incinerators. This contamination is likely to contribute towards atmospheric mercury releases (COWI, 2008), as well as being toxic to aquatic organisms (Norwegian Climate and Policy Agency, 2010). In contrast, mercury-free alternatives have minimal impact on the toxicity of aquatic organisms.

In relation to both health and environmental impacts, mercury-free alternatives have minimal impact relative to mercury.

Examples of regional or national restrictions

In the EU, Regulation (EC) No 2017/852 prohibits manufacturing processes in which mercury or mercury compounds are used as a catalyst from 1 January 2018.

Before Regulation (EC) No 2017/852 came into effect, national legislation in Norway exceeded EU-level restriction, prohibiting the production, use and sale of mercury compounds, which include polyurethane elastomers using mercury (COWI, 2008).

In 2017, Japan implemented the Mercury Pollution Prevention Act, which adopts measures in line with the Minamata Convention, as well as additional stricter measures. In the National Implementation plan, Japan states that ‘no manufacturing process using mercury catalysts has been found in the polyurethane production processes’ (Mercury Convention, 2017, p. 16).

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All other production processes using mercury as an electrode, e.g. production of sodium dithionite, alkali metal

Summary Overview

Mercury electrodes are not only used in chlor-alkali and alcoholates production, which are covered elsewhere in this submission. The only other processes for which evidence was found that mercury electrodes are used are (&) production of sodium dithionite and production of alkali metals.

Sodium dithionite is a reducing agent, which is primarily used in vat dyeing and bleaching (Chavan, 2011). It is primarily supplied as a dry powder, and is known to be effective for stripping colour and removal of multiple types of dyes. Alkali metals are a group of six reactive metals (lithium, sodium potassium, rubidium, caesium and francium). Due to their reactive nature, alkali metals tend to be found combined with other elements. Due to the distinct nature of these metals, their uses vary greatly, including the manufacture of fertilisers, construction of lightweight batteries and the reduction of organic compounds.

Suitable non-mercury alternatives are available for both processes, such as the zinc dust process for the production of sodium dithionite and the electrolysis of liquid sodium chloride.

Under the Minamata Convention, there are no provisions to ban the use of mercury as an electrode in manufacturing processes.

Technical Description

All of the processes which produce sodium dithionite begin with the reduction of sulphurous acid (OECD SIDS, 2006). The amalgam process involves the reduction of sodium hydrogen sulphite, which produces sodium dithionite, using the sodium amalgam from the mercury cell electrolysis of sodium chloride. This process converts the sodium chloride into sodium dithionite and sulphur dioxide, producing a stable material (Bajpai, 2018). The resulting sulphur dioxide is recycled to produce sodium hydrogen sulphite.

The production of alkali metal (sodium, potassium, lithium) is based on the same electrolysis process. An aqueous alkali salt solution (e.g. sodium chloride or lithium carbonate) undergoes electrolysis using a mercury cathode. The alkali metal dissolves in the liquid mercury. In the second process step, the resulting amalgam is switched as an anode and is connected to a liquid cathode made of the corresponding alkali metal by means of a solid ion conducting electrolyte. During the process, alkali metal ions will migrate through the solid electrolyte to the liquid cathode. The process has been described for the production of lithium (BASF, 2001) as well as sodium and potassium (BASF, 2001).

As far as is known, the use of mercury in the process of manufacturing sodium metal in Europe has been implemented at only one facility in Germany, with a production capacity of about 1000 tonnes per year (European Parliament, 2007). The annual global production is approximately 80000-90000 tonnes, produced using all electrode techniques (Thayer, 2008).

Range of mercury content/ consumption per unit product

As the amalgam process uses sodium amalgam from the electrolysis of brine, the upper limit of mercury is expected to reflect the mercury content used in the electrolysis process (i.e. 0.2 ppm) (Brinkmann, et al., 2014). This is the maximum content of mercury in sodium dithionite. It is not possible to calculate the consumption of mercury per tonne of product as there is no publicly available information on production volumes.

Availability of non-mercury alternatives

Main alternatives: Zinc dust, sodium formate, sodium borohydride

An alternative to the use of mercury as an electrode in the manufacture of sodium dithionite is the application of zinc dust. This process involves treating zinc dust in a reactor with sulphur dioxide, to produce zinc dithionite. After treatment, the solution is passed through a filter, to remove the remaining zinc. Following this, the zinc is precipitated from the zinc dithionite, by adding sodium carbonate and sodium hydroxide. After the addition of sodium chloride and further filtering, sodium dithionite is produced (PubChem, 2019).

Another process that produces sodium dithionite is the dissolution of sodium formate in aqueous methanol in a stirred vessel. Sulphur dioxide and sodium hydroxide are added to the solution, to reach a pH of 4-5. These conditions produce sodium dithionite in crystal form, which is then filtered and washed (OECD SIDS, 2006).

The sodium borohydride process involves the addition of sodium borohydride to a strong alkali liquid, which results in the production of sodium dithionite (through the addition of sulphur dioxide and sodium hydroxide).

Mercury-free processes are also available for use in the production of alkali metals (Hagemann & Bischofer, 2013). Sodium, the most important alkali metal is typically manufactured by electrolysis of molten sodium chloride (Downs process). The process takes place at 800°C and is very energy intensive. Lithium may be manufactured the same way while the more reactive potassium is produced by reducing potassium chloride with sodium at 870°C, i.e. the MSA process (Jackson & Werner, 1957).

Technical feasibility of mercury-free alternatives

In 2006, the mercury amalgam process accounted for only 15% of the global production capacity of sodium dithionite. The sodium borohydride process, zinc dust process and sodium formate process accounted for 10%, 35% and 40% respectively (OECD SIDS, 2006). Therefore, the mercury-free alternatives are already commercially available, and the zinc dust and sodium formate processes comprise the greatest capacity to produce sodium dithionite.

In addition, Hagemann & Bischofer (2013) state that alongside the market share for the mercury cell process being relatively small, there are no specific product qualities which are associated with the mercury cell process that alternative processes cannot produce.

Economic feasibility of non-mercury alternatives

As mercury now comprises one of the least used catalysts for the production of sodium dithionite, this suggests that the alternative methods of production are economically feasible.

Production of sodium metal using the amalgam process consumes approximately 40% less energy than the Downs process (Verband Der Chemischen Industrie e.V., 2005). However, about 99% of sodium metal is produced applying the Downs process and is accepted by the market.

Health/Environmental Risks and benefits of non-mercury alternatives

The health effects associated with the alternative processes used to manufacture sodium dithionite are not well documented (PubChem, 2019).

Examples of regional or national restrictions

Under Regulation (EU) 2017/852, the use of mercury as an electrode in manufacturing processes is prohibited from January 2022.

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All other processes using mercury compounds as a catalyst

Summary Overview

Mercury catalysts are not only used in VCM and PUR production, which are covered elsewhere in this submission.

Mercury catalysts may also be used to promote a large range of polymer reactions in production processes (COWI, 2008). For example, vinyl acetate may be produced using mercury salts as a catalyst. Although the use of mercury catalysts was once extensive and covered a multitude of organic reactions (Larock, 1986), there is now minimal use of them, with the exception of the production of polyurethane and vinyl chloride.

This fiche covers the processes that might still be using mercury catalysts: production of 1-aminoanthraquinone and anthraquinone derivates, vinyl acetate and keto acids.

Vinyl acetate monomer is an important material used in the production of polymers, and is used in plastics, paints, varnishes and glues (Kumar, et al., 2006). Similarly, keto acids are used in industry as solvents and in pharmaceuticals. 1-aminoanthraquinone is used for colorants and pigments in a number of products (PubChem, 2019a).

There are substitutes available to the use of mercury in polymer production processes, such as zinc and palladium. In addition, alternative processes can be used to synthesise some materials. The development of substitutes is still ongoing in some cases, in attempts to reduce the complex nature of separating by-products.

Except for acetaldehyde, there is no prohibition outlined in the Minamata Convention concerning manufacturing processes that use mercury as a catalyst.

Technical Description

1-Aminoanthraquinone was produced through the reaction of anthraquinone and oleum (20 wt.-% sulfuric acid), with mercury acting as a catalyst (IFI CLAIMS Patent Services, 2019a). Vinyl acetate may be produced through the reaction of acetylene with acetic acid, in the presence of mercury. Keto acids are synthesised currently by hydration of an acetylene compound, in the presence of mercury (Hunger & Schmidt, 2019).

Range of mercury content/ consumption per unit product

In the EU, there is no knowledge of mercury use in the production of these processes (COWI, 2008).

Availability of non-mercury alternatives

Main alternatives: Palladium chloride/Copper (II) Chloride, Zinc Acetate, Iron (III) Chloride, Alternatives to Keto Acids

Vinyl acetate is nowadays produced through one of the following routes (Dimian & Bildea, 2008):

- Reaction of acetic acid and acetylene catalysed by zinc acetate;
- Reaction of acetaldehyde and acetic anhydride with iron(III) chloride as a catalyst;
- Reaction of acetic acid, ethylene and oxygen with palladium chloride/ copper (II) chloride as a catalyst (the dominating process today).

In the case of 1-aminoanthraquinone, due to the toxic nature of mercury, an alternative process has been adopted. To produce 1-aminoanthraquinone, anthraquinone is nitrated, directly followed by reduction of the nitroanthraquinone (Hunger & Schmidt, 2019).

Technical feasibility of mercury-free alternatives

The alternative process to produce 1-aminoanthraquinone does result in the production of multiple products, requiring hydrogenation. This results in the need for complex methods of separation to produce pure 1-aminoanthraquinone (IFI CLAIMS Patent Services, 2019a).

Zinc and palladium provide technically feasible substitutes for mercury, and are currently used in polymer production processes (COWI, 2008).

Research into alternatives to the use of mercury in the synthesis of keto acids for polymer applications are still ongoing. Therefore, technically feasible alternatives are not currently available and further research developments are necessary (IFI CLAIMS Patent Services, 2019b).

Economic feasibility of non-mercury alternatives

Regulation (EU) 2017/852 prohibits mercury use as a catalyst, which implies that it is economically feasible for EU industry to use mercury-free alternatives.

Health/Environmental Risks and benefits of non-mercury alternatives

The phasing out of the use of mercury as a catalyst in the polymer industry will engender beneficial health and environmental effects. Alternatives such as zinc or iron chloride catalysts do not pose the same health threats linked to exposure or the environmental concerns associated with the release of mercury.

Examples of regional or national restrictions

Under Regulation (EU) 2017/852, processes using mercury as a catalyst are prohibited. Little information exists on the use of these processes in the EU. However, the lack of protest during the negotiations of the Regulation implies that there is no significant use.

In the US' ratification of the Minamata Convention, the US highlights that mercury is no longer used in manufacturing processes, with the exception of two chlor-alkali production facilities, for which it has applied for an exemption (U.S. EPA 2017)

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Use of mercury as propellant in ion engines	
Name of the product use and/or process	Ion engines for satellites and spacecraft
Alternative names	Mercury ion thruster
Purpose of the product/process	Ion thrusters are used for spacecraft propulsion and create thrust by accelerating ions using electricity. Ion thrusters ionize a propellant by adding or removing electrons to produce ions. This is mostly achieved through electron bombardment, where a high energy electron collides with a propellant atom to release electrons and create a positive ion. The most commonly used propellant is xenon, however in the past mercury has be used as a propellant in ion engines (Fazio et al., 2018).
Manufacturers (examples)	Apollo Fusion (United States of America) No manufacture/use in the EU
Mercury content	Consumption: 20 kg of propellant for a representative configuration ideal for a low-orbit satellite (Bloomberg, 2019). According to information from the website of Apollo Fusion, the company intends to produce up to 500 thrusters between 2019 and 2023. This would result in a consumption of around 10 t mercury in less than five years (Apollo Fusion 2019). Plans for satellite constellations are expected to increase the number of satellites in Low Earth Orbit (LEO) by a factor of 10 in the next 10-20 years (Fourie et al., 2019). It has been estimated that 2000 satellites would emit approximately 20 t of mercury per year over a 10 year lifetime which would largely be deposited in oceans.
Environmental or health risk	• Risk of spillage/ contamination on the ground. • Emission of mercury in orbit over the period of 5-7 years, at the height of 300 kilometres to 1,200km above the Earth. Due to the weight of mercury, it is expected to travel back to the surface of the Earth over several years.
Available non-mercury alternatives	• Xenon (Xe) • Krypton (Kr) • Argon (Ar) • Neon (Ne) • Helium (He) • Hydrogen (H_2) • Iodine (I_2) • Buckminsterfullerene (C_{60}) • Adamantane ($C_{10}H_{16}$) • Air (nitrogen/oxygen)
Advantages of mercury compared to alternatives	• A heavy element such as mercury and iodine offers the best engine performance among the alternatives, as they allow a higher payload/ propellant ratio than for example xenon
Additional comments	• Mercury has been used as a propellant in the past, up to around 1980 (Fazio et al., 2018) • NASA began moving away from mercury in the 1970s owing to concerns about contamination on the ground and due to spacecraft interactions (it was replaced by Xenon)
Gaps in information	• Information on the use of mercury as a propellant by Apollo Fusion has been revealed to press by anonymous business insiders. The information has not been validated by the company
References and sources for further information	Apollo Fusion (2019): http://apollofusion.com/ Bloomberg. (2019). *This Silicon Valley Space Startup Could Lace the Atmosphre with Mercury.* Available online at

	https://www.bloomberg.com/news/articles/2018-11-19/this-space-startup-could-lace-the-atmosphere-with-toxic-mercury Fazio et al. (2018). *Alternative Propellants for Gridded Ion Engines.* Available online at https://www.researchgate.net/publication/326571233_Alternative_propellants_for_gridded_ion_engines Fourie et al. (2019). Are mercury emissions from satellite electric propulsion an environmental concern? Published in *Environmental Research Letters.*