EPOXY RESINS IN MARINE COATINGS

ASSESSMENT OF POTENTIAL BPA EMISSIONS

The research on the potential emissions of Bisphenol A (BPA) from manufacturing, using and dismissing epoxy resins in marine coatings was conducted by Beratungsgesellschaft für integrierte Problemlösungen (BIPRO) on behalf of the Epoxy Resin Committee (ERC). This is part of a series which analyses five key application sectors of epoxy resins in Europe. For more information, contact info@epoxy-europe.eu or visit www.epoxy-europe.eu.

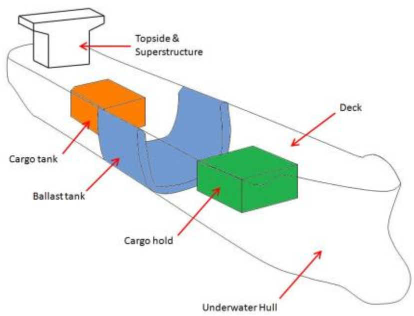
USES & TRENDS

About 51,000 t of BPA-based epoxy resin are used annually in the construction of ships in Europe.[1] Each new ship produced in the EU is estimated to use about 24 t of BPA-based epoxy resins.[2]

Epoxy coatings hold the lion's share of materials used in marine coatings today. Applied since the 1950s, today they are used during shipbuilding, maintenance and repairs on multiple parts of the ship such as underwater hulls, ballast tanks, cargo tanks or holds, decks, topsides and superstructures, etc. They offer excellent resistance against corrosion, provide a long-lasting overcoat and can be conveniently recoated.

Epoxy resins are used as a primer, tiecoat as well as topcoat (against fouling, for decorative purposes and in some cases against UV corrosion).

Ship part	Definition	Epoxy-based coatings
Underwater hull	The structural body of the ship that is responsible for its buoyancy.	
Ballast tanks	The compartment that holds the water ballast to stabilize the ship.	
Cargo tanks	The primary container for the liquid cargo of the ship.	
Cargo holds	The primary container for the dry cargo of the ship (either in containers, sacks, or loose cargo).	
Decks	The horizontal structure covering the ship's hull. Provides the structural strength of the ship and support for people and equipment.	
Topsides & Superstructures	Crew accommodation & permanent structures above the upper deck.	



MANUFACTURING (LIQUID & SOLID EPOXY RESINS)

About 85% of global epoxy resin production – including resin used in marine coatings – is derived from reacting BPA with Epichlorohydrin (ECH). Liquid epoxy resin (LER) is normally produced from a reaction mixing 45% of BPA and 55% of ECH; semi-solid epoxy resin (SsER) would involve reacting 61% of BPA with 39% of ECH. To produce a

[1] Available data report a volume of 97 million litres of epoxy-based marine coatings sold in Europe, the Middle East and Africa in 2014, of which an estimated 84% was sold in Europe only (about 81 million litres). Up to 88% of this epoxy volume would be BPA-based (about 71 million litres). A maximum of 45% of this volume (32 million litres) would contain base epoxy resins (and exclude the mass of solvents, pigments, additives, etc.), which is the equivalent of 51,000 t of BPA-based epoxy resin (36,000 t being SsER and 15,000 t of LER).
Further estimations concluded that a maximum of about 2.8 million t of epoxy marine coatings have been used in Europe at the same time (equivalent to maximum 135,800 kg of residual BPA).

[2] A rough estimate calculated by taking into consideration 377 ships built in Europe in 2013 and assuming that 250,000 litres are needed to coat each ship (equivalent to 20,200 t of epoxy resins).

coating, the epoxy resin is mixed with additional pigments, fillers and/or solvents. In shipbuilding, semi-solid epoxy resins are used for 70% of ships, (36,000 t), while LER is used in the remaining 30% (15,000 t).
BIPRO's analysis took into account the maximum residual levels of 10 and 65 ppm of unreacted BPA for LER and SsER respectively. Taking into consideration the amount of epoxy resins used in marine applications annually in Europe and adopting a highest estimate scenario, the analysis calculates that a maximum of 2,500 kg of residual BPA derived from marine coatings could have been found in Europe in 2014 (150 kg from LER; 2,340 kg from SsER).

BPA assessment:

After the reaction to produce epoxy resins it is washed with water. Residuals dissolved during this washing process are assumed to be disposed of via the waste water treatment at the production site. ERC Members indicated that between 5 and 19 g of BPA per produced ton of epoxy resin was released via on-site waste water treatment in the past ten years, with an efficiency BPA removal rate of 80% to 90%. Assuming a highest estimate scenario (highest BPA quantity and lowest removal rate, also taking into account further treatment by municipal wastewater treatment), it has been estimated that 776 kg of BPA would degrade annually, while 194 kg would leave the wastewater treatment plant and enter water bodies, possibly being broken down by bacteria or other biological means or degradation through UV-light.

Containers used in the production of epoxy are washed with solvents and handled as residual waste according to surveyed industry information. Small amounts of BPA would become sludge and thermally degrade via burning.

APPLICATION STAGE

BPA-based epoxy resin is ubiquitously used in marine coatings as a primer. For any of the ship parts to be coated, the coating protocol would respect a number of strict standard procedures, including: cleaning the steel structure to be coated; curing the resin with a polyamine or polyamine hardener (to increase mechanical, chemical and heat resistance); applying the coating by spray or brushes; drying each coating layer before the next is applied. In more detail:

- Shipbuilding: The primer is mainly a two-component epoxy resin coating to protect steel against corrosion and pollution. BPA release would be very low or non-existent as this process is conducted on dry grounds and the functional coating system is applied over the primer soon after ship assembly. BPA migration through multiple layers of marine coatings is unlikely due to the thickness of the coating and frequent maintenance duties.

- Underwater hull: Coatings are applied to protect against corrosion, fouling, abrasion and other adversities. If maintenance is properly conducted minimal release is expected. 'Ice Class'-classified ships are specially equipped to travel in ice-polar waters with a specially reinforced BPA epoxy topcoat. However only a handful of ships travel year round on icy waters, thus BPA release is negligible.

- Ballast tanks: This part is extremely exposed to seawater corrosion, hence usually coated with two layers of epoxy to increase resistance. They are expected to last 15 years, with rusting on maximum 3% of the total coating surface. Taking into account frequent recoating, potential BPA release is minimal.

- Cargo tanks & holds: These are mainly coated against corrosion but also against substances that may be released during transport (especially the ones corroding steel). They must also protect the goods within the tanks. In most cases these tanks are coated with one layer of epoxy primer and two layers of other coatings. Since 2013, international cargoes must obtain an approval certificate and undergo regular maintenance. There is no available monitoring data of BPA release during service life.

- Topsides & superstructures: These are the parts most exposed to sunlight and UV radiation but also to other weathering conditions. They are usually not coated with epoxy although the latter is sometimes applied for anticorrosion purposes. BPA release is likely to remain low (epoxy is mostly used as primers and tiecoats).

BPA assessment: Loss of paint during application is inevitable. It may spill from brushes or rollers during the transfer to the surfaces to coat, or be blown elsewhere during spraying. Up to 20% of the paint could be lost, corresponding more specifically to 5,100 t of epoxy-based paint during application and another 5,100 t as paint wastage in Europe every year. The latter would be treated as hazardous waste and incinerated, thus degrading 247 kg of residual BPA. Epoxy spills during application would be washed away with water. Assuming the same efficiency data of municipal wastewater removal used for epoxy manufacturing, 151 kg of residual BPA would be removed through wastewater treatment, and a maximum 96 kg of residual BPA would be released into the environment.

SERVICE LIFE

Offshore ships could be exposed to multiple weather conditions such as sea water, mechanical stress, UV exposure, temperature fluctuation, etc.:

BPA assessment: Estimating losses at this stage present numerous uncertainties.

- Saltwater: All parts of the ship are potentially exposed to saltwater, which could result in hydrolysis and water absorption. Release of BPA from cured epoxy resin is negligible, especially at the very low temperatures ships are facing. Water may pass through or be absorbed by epoxy coatings, thus causing the resin to swell. No data are available but potential release of BPA is estimated to remain low, especially if adequate maintenance is carried out.

- Mechanical stress: Hulls, decks and cargo holds are three stress-prone areas, a key factor for degradation of marine coatings (surfaces can be deformed at high temperatures). The likelihood of epoxy coating breaking down in this case primarily depends on the dry film thickness (dft) of the coating, which is usually between 250 and 500 mm. No reliable data is available, although multiple coating suppliers have stated the duration of the coatings to be from 5 to 15 years, which combined with regular maintenance makes BPA release likely to be low.

- Solar radiation: Epoxy-based topcoats on decks can break due to UV exposure, a process which may be also exacerbated by external moisture (e.g. saltwater). It is not possible to offer a precise amount of BPA release as it is unknown how many decks in Europe are fabricated with epoxy, although this remains the most likely source of BPA release at this life cycle stage.

- Changes in temperature: Cured epoxy resins may remain stable at up to 200°C; hence the possibility of BPA release by thermolysis is very unlikely. Regular recoating during maintenance makes it even less likely.

- Maintenance & repair of the ship: The service condition of the ships is inspected by specialised classification societies, which operate regular surveys (usually every 5 years). They often include visual inspections and thickness measurement. Depending on the type of ship and the classification society, if losses of dry film thickness dft of 20-30% are observed the coating conditions would be considered poor. It is not possible to establish how many ships undergo repairs due to breakdown of BPA-based epoxy coatings, although regular maintenance is expected during the life of long-lasting coatings (5-15 years).

END OF LIFE

In 2013, 350 European ships were set for dismantling. Only 18 of them (5%) were dismantled in Europe (mainly Denmark), while the rest was sent to Asia. Specific treatment conditions in Asia are not know but they are known to be less stringent than in the EU, thus risking the release of a maximum 388 kg of residual BPA (from 8,000 total t of epoxy).

BPA assessment: The European Commission has established a framework to regulate handling of end-of-life ships, which can only be dismantled in EU-approved facilities. Marine coatings are considered hazardous substances and contain flammable paints, solvents and other compounds and thus must be treated accordingly at the waste stage. Any BPA present in the coating shall be degraded during incineration (21 kg of residual BPA every year for all 18 ships). It should be noted that this regulation is entering into force in phases. Moreover, this regulation does not apply to ships which do not carry the EU flag, which is a point of major concern in general.

CONCLUSIONS

An estimated maximum amount of 290 kg of BPA could be released annually from marine coatings in Europe. Most potential release of BPA would happen during production of the resin (max. 194 kg, released into water bodies) and during coating (maximum 96 kg). Although release during service life could not be quantified, the most likely release may happen due to UV degradation of epoxy in topcoats. The waste stage presents major uncertainties due to dismantling of ships outside of Europe and the current EU regulatory framework.

Marine coatings

Annual epoxy usage mass (2014)	Annual BPA releases into environment				
	Production	Application	Service life	Waste	Total
51,000 t	max 194 kg	max 96 kg	not determinable	not determinable	> 290 kg

ANNEX: Life cycle stages and related BPA release for epoxy marine coatings