EPOXY RESINS IN WIND ENERGY APPLICATIONS

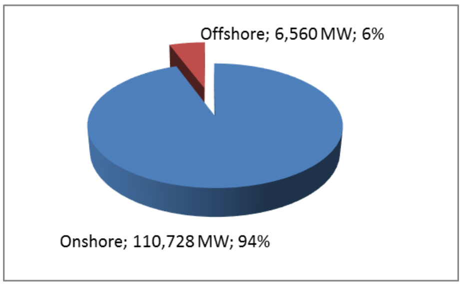
ASSESSMENT OF POTENTIAL BPA EMISSIONS

The research on the potential emissions of Bisphenol A (BPA) from manufacturing, using and dismissing epoxy resins in wind energy applications 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

The majority of epoxy resins found in the energy sector are used in wind turbines. Used since the 1980s in turbine design, epoxy resins are largely employed in composites and adhesives needed to produce wind rotor blades and other structural elements.

EUROPEAN WIND TURBINES CAPACITY UP



Estimates by ERC and BIPRO found that rotor blades in wind turbines active today contain a total of 249,365 t of BPA-based epoxy resins, employing a total of 24,162 t of epoxy resins annually.[1] Rotor blades constitute about 2/3 of all epoxy resins consumed in wind turbines, hence were used as subject of this analysis. Epoxy resins have made it possible to steadily increase the diameter of wind blades over the past 20 years (from ~ 15 m in the 1980s to today's ~ 160 m).

The estimated amount of BPA-based epoxy resin found in rotor blades also matches the results of a recent study about the social and economic benefits of epoxy resins. Developed on behalf of ERC, this report estimates that 24,000 t of BPA-based epoxy resin are used in rotor blades in Europe every year (out of 52,000 t of epoxy resins used in wind turbine design overall). Both figures do not account for imports in and out of the European Union; hence, actual epoxy use in this sector could be higher.

Up to 50% of European wind blade manufacturers nowadays use epoxy resins due to their light weight, resistance to fatigue, good adhesion and lack of shrinkage after cooling. They are most frequently combined with fibre materials such as glass and carbon fibre to produce blades. They are also used to coat and protect other parts including turbine insulators, stator end windings or field coils for rotor brackets. They can cover concrete and steel towers for windmills to increase their lifetime. Finally, the enclosure of the engine housing (nacelle) is made of glass fibre composite material impregnated with epoxy resin.

MANUFACTURING (LIQUID AND SOLID EPOXY RESINS)

The manufacturing of wind turbine rotor blades can be done using two different technologies: vacuum infusion and the so-called 'prepreg' process. The use of vacuum infusion is more frequent, representing about 65% of wind energy installations in Europe (162,087 t), while prepreg is used in the remaining 35% (87,278 t).

In vacuum infusion, the liquid epoxy resin (LER) is mixed with the hardener and sucked into the blade mould via a vacuum pump, impregnating the composite fibres. After heating and curing, the mould is opened to obtain a half rotor blade. Two blade shells, which are produced separately, are then glued together by using epoxy adhesives.

[1] Total consumption was calculated by taking into account potential amounts of cured epoxy resin in average-length blades of existing 50,331 onshore and 1,822 offshore wind turbine installations across Europe - with a total electric generation capacity of 110,728 MW.

In the prepreg technique, fibres are pre-impregnated with BPA-based epoxy resin before further processing. Epoxy resins are usually at semi-solid state (SsER) at room temperature to provide greater firmness to the coating. The manufacturing starts with the manual coating of the outer layer of the blade mould. Mats of prepreg are subsequently placed in the mould, heated and glued to another blade shell and beam to increase strength. SsER is preferred when high viscosity resins are needed.

Epoxy resins used in both techniques require the use of Bisphenol A (BPA) and Epichlorohydrin (ECH) in the first reaction step of the manufacturing process. They are however used in different percentages: 45% BPA and 55% ECH for vacuum infusion and 61% BPA and 39% ECH for prepreg. Research demonstrates that LER may contain a maximum of 10 ppm of unreacted BPA and 65 ppm for SsER. Despite ERC epoxy resin suppliers indicating smaller average amounts in both cases, this study adopted a highest estimate scenario and assumed the maximum amount of potential unreacted BPA. The analysis therefore calculated the presence of a maximum amount of 7,294 kg of residual BPA in rotor blades active in Europe today (1,621 kg in LER and 5,673 kg in SsER).

BPA assessment: After the reaction to produce epoxy resin takes place, excesses of ECH and other substances are washed away with water. According to industry sources, between 5 and 19 g of BPA per produced tonne of epoxy resin are discharged in such fashion. Assuming a highest estimate scenario of 19 g and a minimal efficiency removal rate via on-site wastewater treatment, it has been calculated that from the 249,365 t of epoxy resins used in today's turbine blades, about 4,738 kg of BPA could end up in wastewater after production. Considering further treatment via communal wastewater plants, an additional 3,790 kg of BPA would thus be removed, leaving a total of 948 kg of unreleased BPA which may enter surface water bodies. This would amount to an annual tonnage of 92 kg. The released BPA could be subjected to further biotic and abiotic degradation in water and not persist in the environment; hence the total amount of BPA released from manufacturing of base epoxy resin in wind rotor blades can be said to be negligible.

MANUFACTURING (WIND ROTOR BLADES)

The manufacturing of wind rotor blades may entail further BPA emissions during certain production steps:

- Mixing of epoxy resin with hardener: the epoxy resin and hardener are usually delivered in plastic containers inside a metal grid for stability. After mixing, the containers are taken back by the service provider which disposes of them by incineration or cleans them for reuse. Residues of epoxy resin in these containers - and the tools used for the mixing - are expected to be incinerated, thus destroying any BPA residues.

- Vacuum infusion & prepreg: leftover scraps may remain during the cutting of prepreg mats used to produce each blade. In the vacuum technique, the foil, meshes and resin channels transporting LER into the mould end up as solid plastic waste and destined to incineration. Epoxy resin may sometimes squeeze out of the mould or when gluing two different blades with epoxy resin and generate solid waste. Finally, some exhaust emissions are expected during grinding but no data are available for such dispersed particles.

BPA assessment: Several information gaps affected the analysis of these manufacturing stages. Research established that a 7 t wind blade produced by vacuum infusion would generate a total 4 t of waste, of which 0.4 t appears to be epoxy resins. The total 249,365 t of BPA-based epoxy resin in today's European wind applications could have generated a maximum of 10,473 t of BPA-based epoxy resin waste. Most of this waste would be cured epoxy resin with lower levels of BPA which could potentially be released in the environment (about 306 kg). Disposal methods include incineration – entailing destruction of BPA – but also landfilling, for which the fate of BPA cannot be properly assessed. It should also be noted that this assumption was based on research available on vacuum infusion and not prepreg, for which the same waste assumptions were made.

SERVICE LIFE

Average lifetime of a wind turbine is around 20 years, although good maintenance practices can extend this lifespan. As mentioned above, rotor blade bodies are coated with layers of materials other than epoxy which may better protect them from adverse weathering conditions (rain, ice, sand, sunlight, speed, etc).

BPA assessment: Potential release of BPA is expected to be negligible during service life. The only way to release epoxy particles from running wind turbine blades is by the mechanical stress and scratches of the protective coating, exposing the underlying resin.

END OF LIFE

As per other epoxy applications, the analysis of waste stage highlighted many uncertainties regarding handling and classification of waste to be discarded:

- Legislation: there is no existing legislation dictating disposal methods for wind energy plants, including turbines (end-of-life stage is of no concern yet). Some EU countries decided that combustible components should not be disposed of in landfills; as epoxy resins are combustible, other disposal methods will become necessary in the future.

- Current experiences of disposal: according to a survey by the German Fraunhofer Institute for Chemical Technology, the number of wind energy plants dismantled is very low at this stage. There is not much experience with handling end-of-life energy blades coated with epoxy. Another difficulty is the presence of a market for second-hand turbines in the EU and – most importantly for this analysis – non-EU countries, adding another layer of complexity.

- Ways of disposal: recycling is a possibility for most components of wind energy plants but not for wind rotor blades. Current disposal practices include landfill and incineration, sometimes generating electricity. No statistics are available for disposed or incinerated blades.

BPA assessment: No reliable data were available for this stage. However it was possible to estimate that between 2020 and 2034, Europe will dispose of an estimated 1 million t of end-of-life rotor blades waste. In a worst-case scenario, 162,778 t of BPA-based epoxy resin waste – both LER and SsER – are expected to generate 4,761 kg of BPA. However, it is not clear what fraction of these may be destroyed by incineration or enter water bodies through landfilling. Furthermore, breakdown and leaching of BPA in landfills may generate little emissions because epoxy resin waste is likely to degrade or photooxidate due to direct exposure to sunlight or rainfall. Material recovery methods and pyrolysis experiments are being explored but bear a number of obstacles of both economic and practical nature (e.g. the size of the solid resins).

CONCLUSIONS

A total maximum amount of 948 kg of BPA could have been released into the environment by current uses of epoxy resins in wind rotor blades (a maximum 92 kg per year). Most BPA emissions would result from producing the base epoxy resin used during production. During service life, no relevant BPA losses were expected. The end of life waste stage presents too many uncertainties to determine reliable amounts of BPA losses.

Wind rotor blades

Total epoxy usage mass	Total BPA releases into environment				
	Production	**Application**	**Service life**	**Waste**	**Total**
249,365 t	948 kg	not determinable	negligible	not determinable	> 948 kg

Annual epoxy usage mass (2013)	Annual BPA releases into environment				
	Production	**Application**	**Service life**	**Waste**	**Total**
24,162 t	92 kg	not determinable	negligible	not determinable	> 92 kg

ANNEX: Life cycle stages and related BPA release for epoxy wind rotor blades