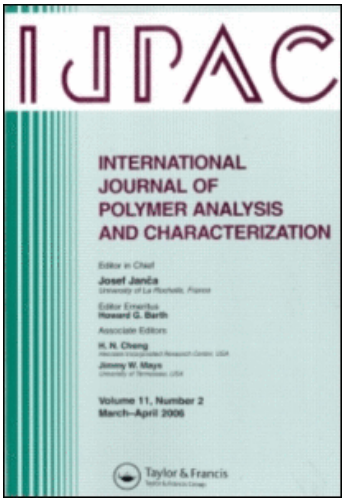

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E. L. Bradley[a]; M. Driffield[a]; N. Harmer[a]; P. K. T. Oldring[b]; L. Castle[a]
[a] Central Science Laboratory, Department for Environment, Food and Rural Affairs, York, UK [b] Valspar, Witney, Oxfordshire, UK

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Identification of Potential Migrants in Epoxy Phenolic Can Coatings

E. L. Bradley,[1] M. Driffield,[1] N. Harmer,[1] P. K. T. Oldring,[2] and L. Castle[1]

[1]Central Science Laboratory, Department for Environment, Food and Rural Affairs, York, UK

[2]Valspar, Witney, Oxfordshire, UK

Abstract: A test protocol has been developed that contains a suite of complementary analytical methods to identify and estimate the concentrations of potential chemical migrants in polymeric coatings applied to metal substrates. The capabilities of these techniques (FT-IR, overall migration, headspace GC-MS, GC-MS, and LC-TOF-MS) have been tested for a variety of polymeric coatings, and the results for one particular coating, an epoxy phenolic, are described as an example. The example provided shows both the power and the limitations of current analytical techniques in the evaluation of the total migrate from food contact materials.

Keywords: Analysis; Can coatings; LC-TOF-MS; Migration

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Address correspondence to E. L. Bradley, Central Science Laboratory, Department for Environment, Food and Rural Affairs, Sand Hutton, York, YO41 1LZ, UK. E-mail: e.bradley@csl.gov.uk

INTRODUCTION

Can Coatings

The majority of cans used to pack foodstuffs are internally coated to form a barrier between the food and the metal of the can. In this way the coating protects the food from the metal substrate as well as protecting the metal substrate from the potentially corrosive foodstuff contained within. Most canned foods are sterilized (e.g., at 121°C for 1 h), and therefore any coating applied to the metal must be able to withstand the elevated temperature and pressure of this process as well as the long shelf-life that canned products offer. The coating formulation may contain various components such as resins, cross-linking agents, catalysts, lubricants, wetting agents, and solvents. The potential exists for these ingredients, by-products of reactions between them, or their degradation products formed during manufacture to migrate from the can coating into the food. Thus, existing as well as new coatings need to be evaluated for their safety for contact with foods and beverages.

The major types of food can coatings are made from epoxy resins. These coatings exhibit a combination of toughness, adhesion, formability, and chemical resistance under the conditions that the coated metal is subjected to. The most widely used epoxy resins are based on bisphenol A diglycidyl ether (BADGE) formed by the reaction of bisphenol A with epichlorohydrin. In addition to the epoxy resins themselves, hardeners such as acid anhydrides, aminoplasts, or phenolplasts may also be included in the formulation as well as additives, such as pigments, fillers, wetting and flow aids, defoamers, and lubricants.

BADGE Migration

The finding in the early 1990s of BADGE migration from certain epoxy-based can coatings[1] led to an explosion of publications (e.g., Biedermann et al.[2] and Philo et al.[3]) on the measurement of BADGE and its known reaction products. These products are formed by BADGE reacting with hydrochloric acid in heated polyvinyl chloride lacquers to form chlorohydrins and with water to form the corresponding diols. BADGE and these known reaction products do not account for all of the potentially migratable substances in an epoxy-based coating. Even though much is known about the toxicology of BADGE, unless the identities of all of the other potential migrants present in food contact coatings are known then the potential toxicity of the total migrate is unknown. Schaefer and Simat[4] published work describing the identification of migrating epoxy-based substances below 1000 Da. Linear and cyclic BADGE oligomers were

present, in agreement with the results of Biedermann et al.,[5] who reported migration of oligomers up to the BADGE tetramer. As well as the BADGE oligomers, reaction products of BADGE with chain stoppers, alcohol and glycol solvents, and phenolic monomers have also been reported.[4,6–8]

Other Migration

Much of the research on the migration from epoxy-based can coatings has centered on BADGE-related substances because they exhibit strong fluorescence and so are easy to detect. However, other substances such as hardeners, additives, and lubricants are also present, and these as well as any impurities and reaction or breakdown products that form from them during coating manufacture also have the potential to migrate into foods.

Safety Evaluation

BADGE and its hydrolysis and hydrochlorination products are regulated by the European Union (EU).[9] There are no specific measures at the EU level to regulate other coating substances or coatings in general in contact with food. Instead, like all food-contact materials and articles, they should comply with the Framework Regulation (EC) No. 1935/2004.[10] Article 3 of this regulation, which is applicable to all food-contact materials, states that food-contact materials shall not transfer constituents to food in quantities that could:

- Endanger human health,
- Bring about an unacceptable change in the composition, or
- Bring about a deterioration in organoleptic characteristics thereof.

How to demonstrate that a can coating does not endanger human health is not defined, and therefore it represents a challenge for the coatings industry. In the absence of specific legislation for coatings the legislation for plastic food-contact materials[11] is often used as a guide. Plastics Directive 2002/72/EC contains a positive list, a list of monomers and additives permitted for use in the manufacture of plastic food contact materials and articles. The list also contains any restrictions that have been assigned following the toxicological assessment of these substances. A Council of Europe resolution on coatings, ResAP (2004) 1,[12] has been prepared, however, this resolution has no legal status. In addition to the list of permitted substances in the plastics legislation, the fourth

amendment to Directive 2002/72/EC[13] includes the explicit provision that there is a general requirement to assess the safety of all potential migrants, including impurities and reaction and breakdown products, and the onus is on the business operator to do so. Again, although this Directive is applicable to plastics, it can also be used as a guide for other food-contact materials and articles. To demonstrate compliance with Directive 2002/72/EC, as amended, these "non-listed substances" should be assessed in accordance with international risk-assessment procedures. In our view such a risk assessment should have three components: (a) the identification of the substances present in the material or article, (b) an estimation of their migration level leading to an estimate of possible consumer exposure, and (c) a risk assessment that considers the potential exposure in context with any hazard (nature and potency) posed by the chemical. The Commission of the EU says it cannot regulate all the different combinations of substances used in food packaging and it wants the industry to take more active responsibility in this area. To this end, as a result of working closely with a major can coating manufacturer, a test protocol has been developed to achieve the first step of this risk assessment, i.e., to identify the potential migrants present in can coatings.

Analytical Strategy

This study focuses on the determination of substances in an epoxy-based can coating containing phenolplasts as a hardener, later referred to as an epoxy phenolic coating. Analytical screening processes have been followed to determine gravimetrically the overall migrate and the mass of the solvent-extractable substances, and headspace gas chromatography-mass spectrometry (GC-MS) was used to detect any volatile substances and solvent extraction, followed by analysis by GC-MS for semi-volatile substances. Mass spectral libraries exist for GC-MS, and therefore identification of any volatile and semi-volatile substances can be derived by comparison with library spectra. Polar and non-volatile substances were investigated using liquid chromatography-time-of-flight-mass spectrometry (LC-TOF-MS).[14] The accurate mass data generated by the LC-TOF-MS instrumentation aids in the identification of the unknown compounds and those where more than one identity is proposed. LC-TOF-MS gives routine mass accuracy of 3 parts per million (ppm) or better over a broad dynamic range to allow accurate mass measurement and has full scan sensitivity to the low picogram level, enabling identification of trace contaminants. For a substance with a molecular weight of 400 Da a 3 ppm mass accuracy is equivalent to $+/-0.0012$ Da.

MATERIALS

Chemicals

Dichloromethane, acetonitrile, methanol, ethyl acetate, ethanol, acetic acid, ammonium formate, and formic acid were all obtained from Fisher (Loughborough, UK), d_{10}-benzophenone and d_{10}-ethylbenzene were from Aldrich (Poole, UK), and isooctane was purchased from BDH (Poole, UK). Bisphenol A diglycidyl ether (BADGE), bisphenol A (2,3-dihydroxypropyl) glycidyl ether (BADGE.H_2O), bisphenol A (3-chloro-2-hydroxypropyloxy) glycidyl ether (BADGE.HCl), bisphenol A (3-chloro-2-hydroxypropyl) (2,3-dihydroxypropyl) ether (BADGE.H_2O.HCl), bisphenol A bis(2,3-dihydroxypropyl) ether (BADGE.$2H_2O$), and bisphenol A bis(3-chloro-2-hydroxypropyl) ether (BADGE.2HCl) were purchased from Fluka (Gillingham, UK).

Coated Metal Panels

Samples of an epoxy phenolic–coated tin plate were provided by Valspar (Witney, UK). The wet (uncured) coating formulation and the individual ingredients were also supplied.

METHODS

Confirmation of Coating Type

The polymer coating on the metal substrate was identified by Fourier transform-infrared (FT-IR) spectroscopy. The coating was removed using an abrasive silicon carbide disk and analyzed using the diffuse reflectance technique.

Gravimetric Determination of Overall Migrate and Solvent Extractables

A method for the determination of overall migration from polymeric coatings on metal substrates has been standardized.[15] For a test sample that may come into contact with all food types migration tests into Simulants B, C, and D are recommended. The epoxy phenolic coated panels were exposed to 3% (w/v) aqueous acetic acid (Simulant B), 10% (v/v) aqueous ethanol (Simulant C), and Simulant D substitutes 95% ethanol and isooctane. Exposures were carried out using a migration cell (contact area 0.4 dm^2, 20 mL simulant) under test conditions equivalent

to the worst foreseeable use of the material, i.e., sterilization followed by long-term storage at ambient temperature. The coated panels were also extracted (total immersion, 0.4 dm^2 extracted into 20 mL of solvent for 24 h at room temperature) using acetonitrile and dichloromethane. Dichloromethane was selected as an extraction solvent because of its aggressive extraction properties. However, it may not possess the qualities to extract large polar substances and therefore acetonitrile was used as well. Acetonitrile has conventionally been used as an extraction solvent for epoxy-based can coatings. The exposed simulant samples and solvent extracts were evaporated to dryness by gentle heating under a stream of nitrogen, and the residues were determined gravimetrically.

Analysis by Headspace GC-MS Analysis

Coated metal panels (total area $\sim$2.5 dm^2) were cut into pieces of approximately 1 cm^2 and mixed. Samples were prepared in three ways: (i) panel (1.5 g) only, (ii) panel (1.5 g) and water (2 mL), and (iii) panel (1.5 g), water (2 mL), and 100 μL of a 1 μg/mL solution of d_{10}-ethylbenzene in ethanol. All samples were prepared in duplicate. Corresponding duplicate blanks (as (i), (ii), and (iii) but without the addition of the coated panel) were prepared in the same way. Following incubation for 30 min at 90°C the resulting volatiles were analyzed using an Agilent 6980 gas chromatograph (Agilent, Palo Alto, Calif., USA) coupled with an Agilent 5973inert mass selective detector by splitless injection of 1 mL of the headspace gas into a DB-VRX capillary column (30 m × 0.25 mm i.d. × 1.2 μm film thickness; J&W Scientific, Folsom, Calif., USA). Following injection, the oven was held at 40°C for 3 min and then raised at 10°C/min to 280°C, where it was held for 5 min. The injector was held at 280°C. Helium (1 mL/min constant flow) was employed as the carrier gas. The MS was operated in electron impact ionization mode with scanned monitoring between 40 and 400 amu.

Solvent Extraction Followed by GC-MS

Coated metal panels (total area $\sim$2.5 dm^2) were cut into pieces of approximately 1 cm^2 and mixed. The pieces were divided into two equal portions and were transferred to two 250 mL conical flasks. 100 μL of a 1 mg/mL solution of d_{10}-benzophenone in acetonitrile was allowed to infuse into the panels, and 100 mL of acetonitrile was added to each flask, ensuring that the panels were totally submerged. The flasks were stoppered and allowed to stand for 24 h at room temperature. Duplicate

blanks were prepared in the same way but in the absence of the coated panel. A portion of the acetonitrile extract was transferred to a 2 mL glass vial and was analyzed by GC-MS. For the determination of the total solvent extractables, extracts were also prepared using dichloromethane in place of the acetonitrile. The extracts and associated blanks were analyzed by GC-MS using an Agilent 6980 gas chromatograph (Agilent, Palo Alto, Calif., USA) coupled with an Agilent 5973 inert mass selective detector. Splitless injection of 1 μL of extract was carried out into a DB-5MS capillary column (30 m × 250 μm i.d., 0.25 μm film thickness; J&W Scientific, Folsom, Calif., USA). Following injection the oven was held at 50°C for 2 min and then raised at 10°C/min to 300°C and held for 5 min. The injector was held at 250°C. Helium (1 mL/min constant flow) was employed as the carrier gas. The MS was operated in electron impact ionization mode with scanned monitoring between 50 and 550 amu.

Solvent Extraction Followed by LC-TOF-MS

Acetonitrile extracts were prepared as described above, and 50 mL of the acetonitrile extract was concentrated to a final volume of 1 mL under a gentle stream of nitrogen. As dichloromethane is not a good solvent for extracting larger polar compounds of the sort amenable to analysis by LC-MS, it was not used here. All extracts were analyzed by LC-TOF-MS using an Agilent LC/MSD TOF (Agilent, Santa Clara, Calif., USA) consisting of a 1200 Series LC and a G120 time-of-flight mass spectrometer. Two separate LC-MS methods were used in order to increase the coverage of compounds that could be detected. In both cases separation was facilitated using an Agilent ZORBAX Eclipse XDB-C18 100 × 2.1 mm, 3.5 μm column. For positive mode electrospray the mobile phase consisted of 0.1% aqueous acetic acid (channel A) and acetonitrile (channel B). For negative mode electrospray the mobile phase was 5 mM ammonium formate at pH 5.5 (channel A) and 0.1% 5 mM ammonium formate at pH 5.5 in acetonitrile (channel B). The mobile-phase gradient for both positive and negative mode electrospray was the same. At time t minutes the percentage A was 0 (80%), 25 (50%), 45 (50%), 60 (0%), 70 (0%), and 80 (80%). The flow rate was 0.2 mL/min with an injection volume of 5 μL.

TOF-MS analysis was carried out in positive and negative mode electrospray with a nebulizer pressure of 45 psi, capillary of 4000 V, gas temperature of 325°C, drying gas flow at 10 L/min, skimmer of 60 V, fragmentor of 150 V and 275 V, and octopole RF voltage of 250 V. The mass range measured was 100–1100 m/z. The TOF-MS data produced

were processed using Agilent Molecular Feature Editor software, and the parameters given in Table I.

Table I. Molecular feature editor parameters used in the LC-TOF-MS data analysis

Parameter	Value
Number of C atoms	0–100
Number of H atoms	0–200
Number of O atoms	0–20
Number of N atoms	0–20
Number of Cl atoms	0–5
Number of Na atoms	0–1
Number of K atoms	0–1
Signal/noise threshold	50
Minimum relative volume	5%
Mass accuracy tolerance	5 ppm

Analysis of BADGE and Its Derivatives

Coated metal panels (total area 10 dm^2) were cut into pieces of approximately 1 cm^2 and mixed. The pieces were divided into four equal portions and transferred to four 250 mL conical flasks. Acetonitrile (100 mL) was added to each flask, the flasks were stoppered, and the contents were mixed. Extraction was carried out for 24 h at room temperature. Then 50 mL of the extract was concentrated to a final volume of 1 mL, which was transferred to a glass vial suitable for high-performance liquid chromatography with fluorescent detection (HPLC-FLD) analysis. Overspikes were prepared by adding 100 µL of a solution containing BADGE, BADGE.H_2O, BADGE.HCl, BADGE.H_2O.HCl, BADGE.2H_2O, and BADGE.2HCl, each at a concentration of 10 µg/mL. Blank samples were prepared in the same way but in the absence of the coated panel. The concentrated extracts were injected onto the HPLC column. Analysis was carried out using an HP1100 HPLC system with a fluorescence detector set at excitation 275 nm and emission 305 nm. The injection volume was 20 µL. The column was a Sunfire (Waters, Elstree, Hertfordshire, UK) C18 150 × 4.6 mm, 5 µm, and and the mobile phase was 1 mL/min of a gradient of water (A) and acetonitrile (B). The gradient elution program was that at time t minutes the percentage A was 0 (80%), 10 (65%), 25 (50%), 45 (50%), 60 (0%), 70 (0%), and 80 (80%). Calibration was realized by the analysis of acetonitrile containing known amounts of

BADGE, BADGE.H_2O, BADGE.HCl, BADGE.H_2O.HCl, BADGE.$2H_2O$, and BADGE.2HCl.

RESULTS AND DISCUSSION

A test protocol is proposed that contains a suite of analytical methods to identify and quantify chemical migrants from polymeric coatings on metal substrates. This suite of analytical techniques includes FT-IR analysis for characterization of coatings as the first step. In all cases the gravimetric determination of the overall migration and total solvent (dichloromethane and acetonitrile) extractable substances present in the coatings; screening analysis including GC-MS with headspace and liquid injection analysis; and LC-TOF-MS are recommended. The list of specific analyses that should be performed is dependent on the coating type and on the identities of the substances detected in the screening exercise.

The test protocol was:

1. Confirm the coating type by FT-IR spectroscopy.
2. Assemble, if possible, the formulation details along with a description of the manufacturing process, especially with regard to the coating thickness, the time/temperature conditions of stoving, and the intended food or beverage packaging applications.
3. Determine the overall migration and total solvent extractables.
4. Determine the identities and estimated levels of any volatile potential migrants in the coated panels by headspace GC-MS.
5. Determine the identities and estimated levels of any semi-volatile potential migrants in the coated panels by solvent extraction followed by GC-MS.
6. Determine the identities and estimated levels of any polar and/or non-volatile potential migrants in the coated panels by solvent extraction followed by LC-TOF-MS.
7. Based on an evaluation of the information in (2) above and that derived from the generic screening procedures described in (3)–(6), decide which, if any, specific analyses should be performed. This evaluation and decision process should be documented.

Note that specific analyses should be carried out for those substances expected to be present from the formulation details or detected in the screening exercise that have been assigned exposure restrictions and/or specific migration limits. For example, Directive 2002/72/EC, as amended, the Synoptic Document contains the provisional list of

monomers and additives notified to the European Commission as substances that may be used in the manufacture of plastics or coatings or listed in the Technical Document No. 1–List of substances to be used in the manufacture of coatings intended to come into contact with foodstuffs, a supporting document to the Council of Europe Resolution. Where available, standard methods (such as CEN standards or Technical Specifications) should be used to determine these substances. In cases where standard methods are not available then specific methods should be developed and validated in-house according to recognized validation protocols (e.g., Thompson et al.[16]). For example, for epoxy and organosol coating types the levels of BADGE and its derivatives should be determined.

This test protocol has been applied to several generic coating types as well as new coating formulations developed within the Defra LINK project FQS45 "New technologies and chemistries for food can coatings." In this article the results of the application of this protocol for one of these coatings, a generic epoxy phenolic coating, are presented.

Confirm Coating Type by FT-IR Spectroscopy

The FT-IR spectrum obtained is shown in Figure 1. Comparing the spectrum with that of an in-house library confirmed that the coating was an epoxy phenolic.

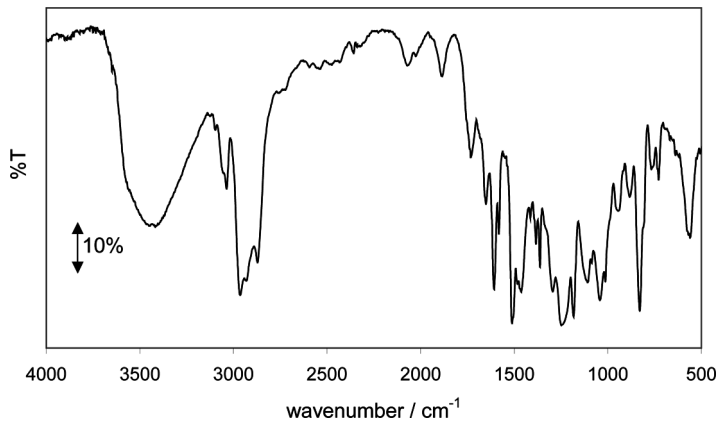


Figure 1. FT-IR spectrum of the epoxy phenolic coated tinplate.

Assemble Formulation Details and a Description of the Manufacturing Process

For this screening exercise a deliberately complex combination of a multi-component epoxy phenolic resin was chosen. The epoxy phenolic coating was described as containing a modified epoxy resin, three different phenolic resins, melamine formaldehyde resin, a phosphoric acid catalyst, a defoamer additive, several solvents (aromatic and ester-based), glycol ether and its acetate, and four different wax additives. Most epoxy phenolic–based can coatings are stoved at temperatures in excess of 200°C for up to 12 min to facilitate the curing process.

Determine Overall Migration and Solvent Extractables

The Council of Europe Resolution[12] on coatings has set an overall migration limit of 10 mg/dm^2 (the same limit is assigned for plastic food contact materials). Exposure to simulants B and C gave migration values in excess of this limit due to corrosion of the base metal substrate, therefore these high aqueous simulants were not considered to mimic migration into foods. The olive oil substitutes isooctane and 95% ethanol, which were used as it is not technically feasible to test the migration from polymeric coatings on metal substrates using olive oil, did not give any detectable migration (Table II). There is no limit on the total mass of the solvent extractable substances from these coatings but even with an aggressive solvent such as dichloromethane used to represent the worst case the total mass of extracted substances was less than the 10 mg/dm^2 limit. These values are also provided in Table II.

Table II. Overall migration/solvent extractables from the epoxy phenolic coating

Simulant/extraction solvent	Simulant/extraction conditions	Overall migration/ solvent extractables (mg/dm^2)
Isooctane	2 h at 60°C followed by 2 days at 20°C	<2.5
95% Ethanol	4 h at 60°C followed by 10 days at 40°C	<2.5
Acetonitrile	24 h at room temperature	5.0
Dichloromethane	24 h at room temperature	8.5

Determine Any Volatile Potential Migrants in the Coating

No volatile substances were detected in the chromatograms obtained from the headspace GC-MS analysis of the epoxy phenolic coating at a concentration (estimated relative to the internal standard) in excess of 1 μg/6 dm^2, therefore the volatiles released were not considered to be present at toxicologically significant levels. It is assumed, as is the convention, that 6 dm^2 of food-contact material comes into contact with 1 kg of foodstuff and therefore a concentration of 1 μg/6 dm^2 is equivalent to 1 μg/kg in the food, assuming 100% migration. Alternatively, a typical can size of 450 g has an area of 3.5 dm^2, and therefore a concentration of 1 μg/6 dm^2 is equivalent to 1.3 μg/kg in the food, again assuming 100% migration.

Determine Any Semi-volatile Potential Migrants in the Coating

The proposed identities (determined by comparison with library spectra) and estimated concentrations (relative to the internal standard) of the substances detected in the solvent extracts are given in Table III. Bisphenol A, a starting substance in the manufacture of the BADGE monomer used to make the epoxy resin, was detected. Five other substances were also detected; no good library matches were obtained for any of these, but the ions in the mass spectra were consistent with those expected for alkyl-substituted phenols. Solvent extracts of the raw materials used to manufacture the epoxy phenolic coating were also analyzed by GC-MS (the same analytical method was used). All five of these substances were also present in one of the phenolic resins used. From the known starting materials used to make this resin a number of possible reactive structures could be predicted (examples are shown in Figure 2), i.e., reaction of the phenolic substance with formaldehyde and an alcohol to yield *ortho*- and/or *para*- substituted phenols. These predicted substituted phenols (phenolplasts) were all detected in the solvent extracts of the phenolic resin but were not in the coated panels. All of these substances have functional groups capable of reacting with the epoxide moiety of the epoxy resin to form the polymer. The fact that these five substances remain in the cured can coating suggests that they do not possess this reactive functionality. Examples of such substances are given in Figure 3. It is well known that in addition to being components of some phenolic resins, reduced functionality phenolics, such as p-t-butyl phenol, are used as ''chain stoppers'' for epoxy resins. Hence, the presence of such species has three potential sources, either the phenolic or the epoxy resins or both.

Table III. Potential migrants detected (by GC-MS) in dichloromethane and acetonitrile extracts of epoxy phenolic coated panels and their estimated concentrations

Retention time (minutes)	Ions	Best library match	Estimated concentration in the dichloromethane extract (μg/6 dm^2)	Estimated concentration in the acetonitrile extract (μg/6 dm^2)
15.4	121, 149, 177	Alkyl substituted phenol—present in phenolic resin starting material	5.1	<LOD
17.5	163, 178, 191, 206	Alkyl substituted phenol—present in phenolic resin starting material	8.4	<LOD
18.3	147, 175, 193, 208	Alkyl substituted phenol—present in phenolic resin starting material	22	13
19.6	91, 108, 163, 177, 192, 222	Alkyl substituted phenol—present in phenolic resin starting material	4.0	<LOD
23.2	91, 119, 213, 228	Bisphenol A—present in epoxy resin starting material	17	12
26.9	175, 191, 235, 293, 335, 353, 368	Alkyl substituted phenol—present in phenolic resin starting material	12	15

LOD in dichloromethane = 2.0 μg/6 dm^2; LOD in acetonitrile = 2.1 μg/6 dm^2.

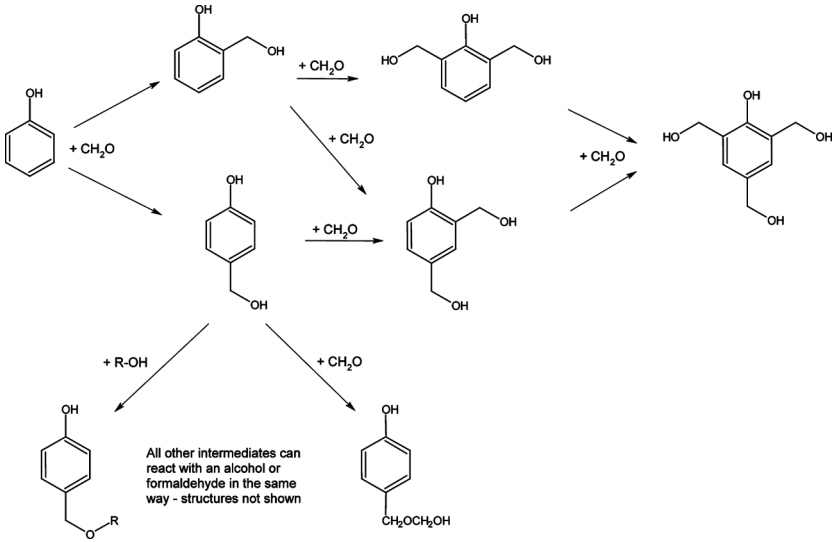
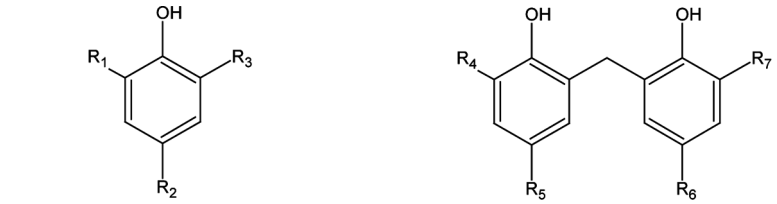


Figure 2. Reaction scheme for the formation of phenolic intermediates (ortho- and para-substituted phenols may also be used and can react in the same way).



2,4,6-alkyl substituted phenol - no ortho- or para- positions available for reaction with formaldehyde

substituted diphenol - no ortho- or para- positions available for reaction with formaldehyde

Figure 3. Examples of relatively unreactive phenolic resin substances.

Determine Any Polar and/or Non-volatile Potential Migrants in the Coating

The TOF-MS data produced were processed using Agilent Molecular Feature Editor software. This package examines the data, extracts chromatographic peaks, and produces mass spectra for those peaks. The accurate mass data are then either compared to a user-produced database of expected structures or compared to a molecular formula database to predict probable formulae. Where appropriate the fragment ions have

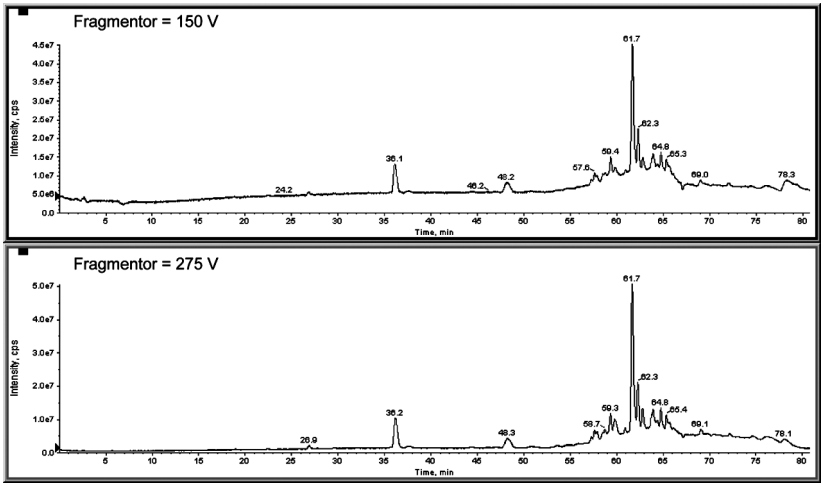


Figure 4. LC-TOF-MS total ion chromatogram of the acetonitrile extract of an epoxy phenolic–coated tinplate with fragmentor values of 150 V and 275 V.

been identified using accurate mass measurements. These data complement the structural confirmation from the accurate mass of the molecular ions. Some of the chromatographic peaks seen in the extracts are very small but are elucidated nevertheless, highlighting the power of TOF-MS. Many of the peaks are not visible from the total ion chromatogram (TIC) but are extracted from the raw data by the data processing software. Figure 4 shows the TIC resulting from the analysis of the acetonitrile extract of the epoxy phenolic–coated panels at fragmentor values of 150 V and 275 V. At the higher fragmentor value the peak in the MS corresponding to $M + NH_4^+$ disappears and fragments at lower mass are seen. These fragment peaks were elucidated and the data generated was used to add further confidence to the identities proposed. A database of potential structures was prepared from the information known about the raw materials used to prepare the coating. This database, in conjunction with the TOF-MS data (accurate mass determinations of molecular ion adducts and fragment ions) and MS data (not TOF) reported in the literature,[4] was used to assign the identities of the 34 chromatographic peaks that were detected when the extracts were analyzed by electrospray operated in the positive mode. Analysis of the extracts by electrospray operated in the negative mode did not detect any additional substances, and therefore the data generated are not described.

Of the 34 substances detected, 27 were found to contain the BADGE unit and were proposed to be reaction products of the BADGE monomer (or dimer) with other ingredients in the coating (Table IV). The majority

Table IV. Retention time, predicted formula, and proposed identity of chromatographic peaks detected in the extracts of the epoxy phenolic coating

Peak number	Retention time (minutes)	Predicted formula	Proposed identity
1	17.8	$C_{21}H_{28}O_6$	BADGE·2H_2O
2	21.0	$C_{21}H_{26}O_5$	BADGE·H_2O
3	26.2	$C_{25}H_{36}O_7$	BADGE·H_2O·EtOEtOH
4	31.5	$C_{22}H_{30}O_5$	Cyclic compound from carnauba wax
5	33.7	$C_{27}H_{40}O_7$	BADGE·H_2O·BuOEtOH
6	34.4	$C_{29}H_{44}O_8$	BADGE·2EtOEtOH
7	34.8	$C_{25}H_{36}O_6$	BADGE·H_2O·BuOH
8	42.0	$C_{27}H_{38}O_6$	BADGE·BuOEtOH
9	42.6	$C_{27}H_{38}O_6$	BADGE·BuOEtOH
10	43.3	$C_{24}H_{34}O_5$	BADGE·H_2O·PrOH
11	44.2	$C_{36}H_{40}O_6$	Linear or cyclic BADGE·BPA
12	45.3	$C_{29}H_{44}O_7$	BADGE·EtOEtOH·BuOH
13	45.4	$C_{36}H_{42}O7$	BADGE·H_2O·BPA
14	46.4	$C_{28}H_{42}O_7$	BADGE·MeOEtOH·BuOH
15	47.6	$C_{29}H_{42}O_8$	BADGE·MeOMeEtOPrOH
16	50.5	$C_{37}H_{48}O_9$	Unknown
17	54.0	$C_{22}H_{46}O_7$	Polyoxyethylene (6) decyl ether
18	55.1	$C_{31}H_{48}O_8$	BADGE·EtOEtOH·BuOEtOH
19	55.8	$C_{27}H_{38}O_6$	BADGE·BuOEtOH
20	55.9	$C_{27}H_{39}O_6Cl$	BADGE·BuOEtOH·HCl
21	56.6	$C_{29}H_{44}O_7$	BADGE·EtOEtOH·BuOH
22	57.0	$C_{25}H_{34}O_6$	BADGE·EtOEtOH
23	57.1	$C_{27}H_{39}O_6Cl$	BADGE·BuOEtOH·HCl
24	58.1	$C_{27}H_{38}O_6$	BADGE·BuOEtOH
25	58.7	$C_{31}H_{44}O_8$	Unknown
26	60.0	$C_{45}H_{60}O_{10}$	BADGE(n = 2)·H_2O·BuOEtOH
27	61.2	$C_{33}H_{52}O_8$	BADGE·2BuOEtOH
28	61.3	$C_{42}H_{52}O_9$	BADGE(n = 2)·MeOEtOH
29	61.6	$C_{31}H_{48}O_7$	BADGE·BuOH·BuOEtOH
30	62.2	$C_{42}H_{54}O_8$	BADGE·BPA·BuOEtOH
31	62.7	$C_{27}H_{38}O_5$	BADGE·HexOH
32	63.1	$C_{36}H_{57}O_9Cl$	Unknown
33	63.4	$C_{43}H_{60}O_{10}$	Unknown
34	65.1	$C_{51}H_{72}O_{11}$	BADGE(n = 2)·2BuOEtOH

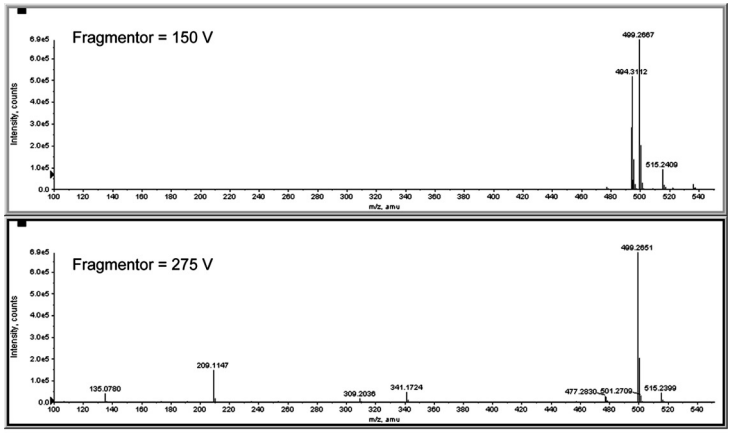
BADGE: bisphenol A diglycidyl ether; BADGE(n = 2): BADGE linear dimer; BPA: bisphenol A; BuOEtOH: butoxyethanol (or other $C_6H_{14}O_2$ isomers; see Figure 7); BuOH: butanol; DiIsoPrPh: diisopropylphenol; EtOEtOH: ethoxyethanol (or other $C_4H_{10}O_2$ isomers); HexOH: hexanol; HydroxyPh: hydroxyphenol; MeOEtOH: methoxyethanol (or other $C_3H_8O_2$ isomers); PrOH: propanol.

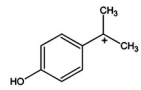
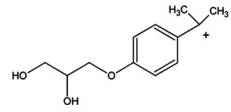
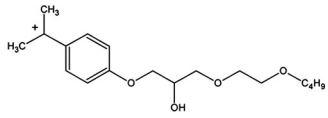
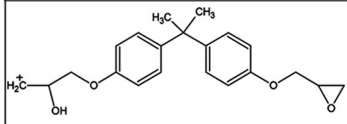
of these are assigned to reactions between BADGE and organic solvents, but chlorinated and hydrolyzed derivatives were also detected. Although not included in the formulation, small amounts of chlorinated BADGE can be formed during the synthesis of BADGE by reaction between bisphenol A and epichloroydrin. BADGE and bisphenol A were also seen to react together to form a substance that has been called cyclo-di-BADGE.[4,17] The mass spectra obtained for one of these peaks analyzed at the two fragmentor voltages are shown in Figure 5. The structures assigned to the fragment ions detected at the higher voltage provide additional evidence that the chromatographic peak is BADGE related.

The peaks labeled as numbers 8, 9, 19, and 24 in Table IV all have the same MS characteristics and are proposed to be BADGE.Butoxyethanol (BADGE.BuOEtOH). Peaks 20 and 23 also have the same MS characteristics, and both were assigned as BADGE.BuOEtOH.HCl. There are several possible explanations for this:

- As well as BuOEtOH forming an adduct with BADGE, other $C_6H_{14}O_2$ solvent isomers, i.e., PentOMeOH, PrOPrOH, EtOBuOH, MeOPentOH, and hexanediol (Figure 6), may have also reacted in this way. They have been assigned as the BuOEtOH adduct as this is a known ingredient in the formulation. The other $C_6H_{14}O_2$ isomers may have been present as minor impurities in the solvent.
- The epoxy resins used in the lacquer may not have consisted of *p*,*p*-BADGE isomers exclusively, but may also have had small amounts of the *o*,*o*- and/or *o*,*p*-isomers present. Figure 7 shows the possible isomers for BADGE. This has been reported in the literature before.[4,18]
- Regio-isomers may have formed as the hydroxyl group of the attacking alcohol added to position 1 or 2 of the epoxide ring during the reaction of BADGE with the solvents. They are shown in Figure 8. These have also been reported in the literature.[4,17,19]

For the six peaks that were not assigned as BADGE related, using the database of known starting materials, their molecular formulae were proposed from the TOF-MS accurate mass determinations of the molecular ion adducts. Solvent extracts of the starting materials were also analyzed by LC-TOF-MS to establish whether or not the source of these substances could be determined in this way or if they were reaction/breakdown products formed during the stoving process. Structures were proposed that suggested the presence of a surfactant polyoxyethylene (6) decyl ether and a cyclic compound from carnauba wax. Neither of these



Ion	Mass
	135.0780
	209.1147
	309.2036
	341.1724
M+H	477.2830
M+H4N	494.3112
M+Na	499.2651
M+K	515.2399

Formula	Compound	Error (mDa)	Error (ppm)
C27H40O7	BADGE.H_2O.BuOEtOH	0.88	1.9

Figure 5. LC-TOF-MS mass spectra obtained for peak 5 eluting at retention time 33.7 min and proposed identities of molecular ion adducts and fragment ions.

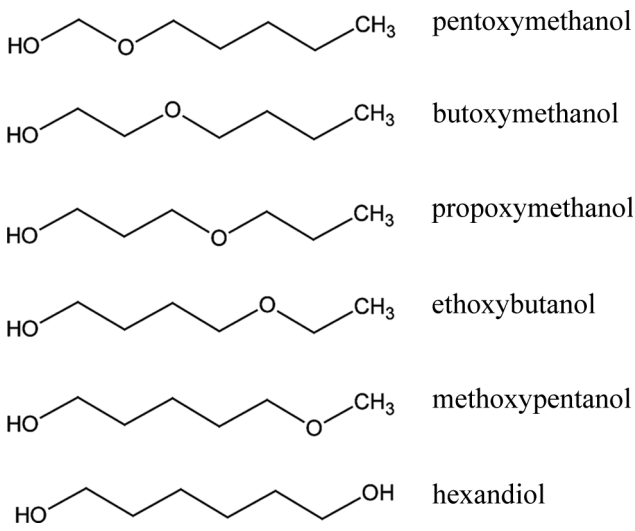


Figure 6. Structures of the $C_6H_{14}O_2$ isomers described as butoxyethanol.

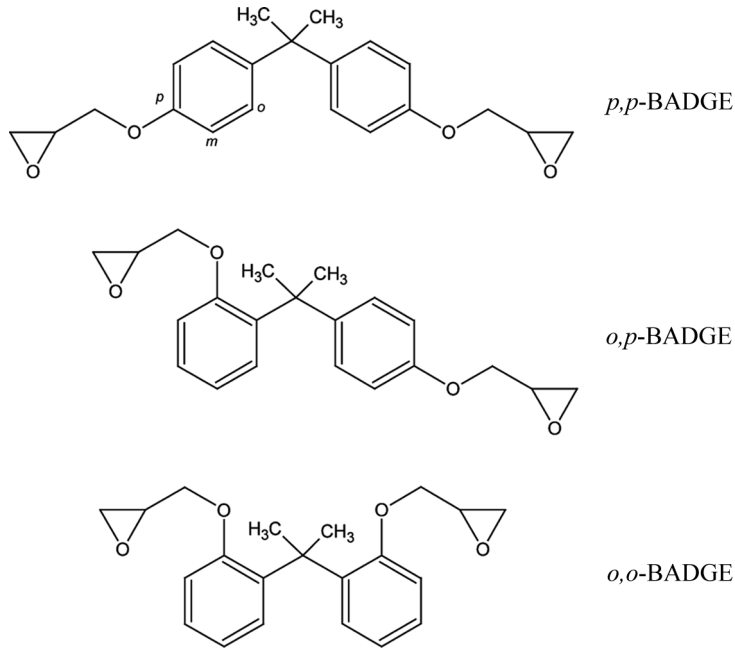


Figure 7. Isomers of BADGE; the *p*, *p*-isomer is the major component in technical grade BADGE.

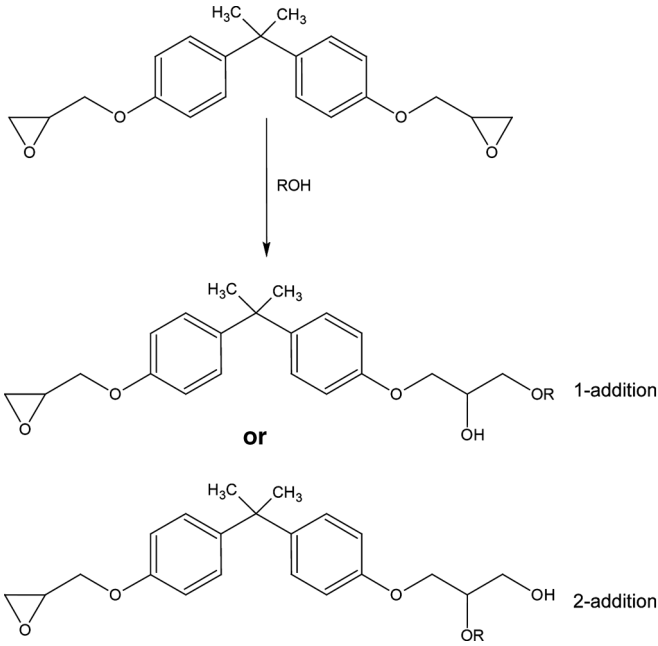


Figure 8. Isomers of BADGE alcohol adducts.

substances was detected when the starting materials were analyzed in this way, suggesting that as non-reactive substances they have been enriched in the cured coating or that they were present in the extracts but were masked during the analysis by other substances. The exact identities of the remaining four peaks could not be determined. The concentrations were estimated relative to a BADGE standard analyzed throughout the analytical batch. None of the individual substances was present with migration potentials in excess of 10 μg/kg.

Evaluation of the Formulation Data and the Results of the Analytical Screening Exercise to Assess the Need for the Application of Any Additional Specific Tests

Only generic names for substances present in the coating formulation were provided, and therefore the identities of any specific potential migrants could not be defined from this source. The formulation details do list the inclusion of an epoxy resin, and therefore targeted analysis of BADGE and its derivatives was carried out.

As no substances were detected in the headspace GC-MS analysis using a method with a detection limit equivalent to a worst-case migration of 1 μg/kg, no further work was carried out to determine the migration of volatile potential migrants.

One of the six substances detected by solvent extraction followed by GC-MS was bisphenol A. This substance has been assigned a specific migration level (SML) in the EU plastics legislation of 0.6 mg/kg, and it has a toluene diisocyanate index (TDI) value of 0.05 mg/kg b.w.[20] Given that the concentration of bisphenol A in the coating was estimated to be 0.017 mg/dm^2, it was not considered necessary to determine the specific migration of this substance.

A similar consideration for other substances used that have an SML, including melamine, formaldehyde, and several phenols, led to the conclusion that the specific migration test for these substances was not needed (data not shown).

A further five substances were detected in the dichloromethane extracts (two of the five substances were also detected in the acetonitrile extracts) for which no good library matches were obtained. Their spectra were consistent with those expected for alkyl-substituted phenols. The calculated worst-case migration potentials of three of the five substances were less than 10 μg/kg, and as a result these were not considered further. The other two were present in the coating at levels that gave rise to migration potentials of 17 and 22 μg/kg. Several substituted phenolic compounds are listed in the positive list for plastics and the Council of Europe Technical Document No. 1 list of substances to be used in the manufacture of coatings intended to come into contact with foodstuff*s*. Of these the lowest SMLs assigned (0.05 mg/kg), for 4-t-butylphenol, 4-cumylphenol, and 2,6-dimethyphenol, are greater than the worst-case migration potentials for the substituted phenols detected here. None of the substances detected by LC-TOF-MS was present at estimated concentrations in excess of 10 μg/kg, and therefore the five unknown substances were not considered further.

Specific Tests: BADGE and BADGE-Related Compounds

A number of potential BADGE-related migrants were detected in the solvent extract of the epoxy phenolic coated panels but at very low levels. Only BADGE.H_2O detected at a concentration of 6 μg/kg was present at levels above the analyte limit of detection. The worst-case limit of detection for the other BADGE-related substances was 9 μg/kg, clearly below the SML(T) of 9 mg/kg for BADGE and its hydrolysis products and the SML(T) of 1 mg/kg for the BADGE hydrochlorination products.[9]

CONCLUSIONS

In the absence of specific legislation on can coatings, manufacturers must assess the safety of their products in accordance with international risk-assessment procedures. The procedures described in this article are suitable for the identification of potential migrants across a wide range of molecular weights and different polarities and also provides an estimation of the levels present. Even applying new analytical techniques such as LC-TOF-MS using software capable of accurate mass determination to an accuracy of 3 ppm, with knowledge of the starting materials used to manufacture the coating, and working closely with representatives from the coating industry, it was not possible to identify every solvent extractable substance present in the epoxy phenolic coating. However, compared to previous reports, the use of LC-TOF-MS has allowed the identification of a large number of previously unknown peaks in the chromatograms obtained form the analysis of can coating extracts. By considering the levels of the identified and the unknown substances present in the coatings an estimation of their migration can be calculated. In this way data was generated to support the use of the generic epoxy phenolic coating assessed in this study in food-contact applications.

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