AIR PRODUCTS

# Waterborne epoxies

*a practical, economic solution*
*to low emission industrial floorings*


**Authors:** Stephen Monaghan b (monaghs@airproducts.com)
Rob Rasing a (rasingr@airproducts.com)

**Presented by:** Rob Rasing
Applications Development Chemist

**Company:** Air Products and Chemicals, Inc.

a c/o Kanaalweg 15
3526KL Utrecht, The Netherlands
Tele +31 30 2857100

b c/o Clayton Lane
Clayton, Manchester M11 4SR, UK
Tele +44 780 1178317



**Presented at:** European Coatings Congress
Nürnberg, 30 March - 1 April 2009

## Abstract

Current VOC legislation and material hazard classification are the tangible results of ongoing efforts to establishing a safe environment for professional applicators working with reactive systems. Increased environmental awareness in society and industry has turned the spotlight on "green" technologies that meet the safety requirements both during the construction stage and during the lifetime of the building in service. Emerging EU regulations for the protection of inhabitants against hazardous emissions from building materials, targets the enforcement of high indoor air quality. Waterborne epoxies have long been recognised as the technology of choice for high performance flooring systems offering features including low odour, VOC compliance, easy handling and clean up. In addition this paper will present recent advancements of waterborne epoxies that demonstrate the ability to formulate high performance systems which are compliant to anticipated emission and out-gassing limits. Further, this paper will present the performance advantages of the latest waterborne epoxy curing agents offering high mechanical and chemical protection for concrete.


## Introduction

For more than a decade, the coating industry has been working to reduce the volatile organic compounds, VOC, of formulated paints, varnishes and refinishing products in accordance with European guidelines. The solvent emissions directive, 1999/13/EC, introduced limits for volatile organic solvents from a so called installation or stationary unit where a VOC was defined by its vapour pressure at ambient temperature. Council Directive 2004/42/EC, also referred to as the "deco paint directive", specifies VOC by its boiling point at ambient pressure and sets maximum limits of VOCs released into the environment for different types of coatings and varnishes. In both cases, the VOCs are released during the application of the paint or varnish until the point of dry film formation. In this respect, low VOC paints contribute positively to worker safety. In the area of two-pack epoxy coatings and flooring products, the ongoing legislative and technical advances has made waterborne systems a fundamental solution to the market requirements. Many waterborne epoxies are formulated without volatile solvents and use merely water as a diluent leading to ultra-low, or even zero, VOC paints and varnishes [1].

When a paint or flooring product is applied and has formed a dry film, the structure is taken back into service. Construction products, once applied, may be considered as inert materials with long service times, although there are exceptions. This was recognized in directive 1989/106/EEC essential requirement number 3, which targets protection of inhabitants from exposure of hazardous emissions coming from building materials [2]. At the moment, many activities are ongoing at the European level to build our understanding in these areas in order to develop sound legislation for the future. With respect to the construction industry, the technical working group of the European committee for standardisation (CEN TC 351) is charged with completion of EU mandate M/366 [3]. This is essential to develop new methods to assess hazardous emissions from construction products. In support of this, the European Collaborative Action (ECA) has published several documents where Reports 18 and 24 have particular relevance to emission from flooring products [4,5].

Coatings and flooring products based on two-pack thermoset epoxies have been widely used in the construction industry. Their excellent adhesion with high mechanical strength and chemical resistance offer solid protection of the concrete substrate. Here, conventional technologies are frequently formulated with non-reactive components. These components often include plasticisers required for delivering high performance, but these may also contribute to emissions during the lifetime of the building in service. The primary objective of the paper is to address these shortfalls using a 2-pack waterborne epoxy system that delivers high end-performance, required for good protection.

# *First choice for application on to concrete*

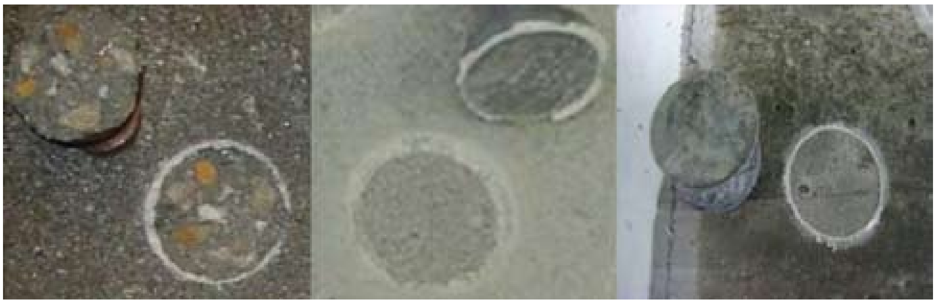
## *Superior adhesion*

Concrete primers offer two primary functions. Firstly, excellent adhesion to the substrate while offering a limited amount of protection. Secondly, the primer should offer a sound surface which can readily be coated with further protective or decorative coatings to produce a finished flooring system. Waterborne epoxy systems based on water soluble amines are well known for having excellent adhesion onto a wide range of substrates and bring great value in primers [6,7,8,9]. A waterborne curing agent, WBCA-1 [1], has been designed to be used in high performance primer system while giving a very low cost-in-use. Systems based on this curing agent provide excellent adhesion to mineral substrates such as concrete, anhydrite, ceramic and old epoxy coatings. In addition to this, systems based on WBCA-1 will provide excellent adhesion on to damp concrete, which is often encountered when coating industrial concrete floors. The adhesion data presented in Table 1 clearly demonstrates that compared to traditional solvent free and solvent borne primer systems the adhesion to damp concrete is superior with the mode of failure for WBCA-1 systems being cohesive. This indicates that the adhesive strength to the concrete is greater than the tensile strength of the concrete itself. The primer systems shown are based on stoichiometric use of the curing agents with an unmodified bisphenol A diglycidylether epoxy resin. Figure 1 shows the pull-off adhesion testing of WBCA-1 compared to a standard cycloaliphatic system when applied to damp concrete.

*Table 1.*

| Curing agent technology | Standard Dry Concrete | Standard Damp Concrete |
|---|---|---|
| WBCA-1 curing agent | 8 MPa – concrete failure | 8 MPa – concrete failure |
| Solvent free Cycloaliphatic | 8 MPa – concrete failure | <1 MPa – adhesive failure |
| Solventborne polyamide | 8 MPa – concrete failure | 3 MPa – partial adhesive failure |

*Figure 1.*



**WBCA-1 Primer System** | **Solvent free Cycloaliphatic** | **Solventborne Polyamide**

The robust nature of the adhesion of WBCA-1 based primer systems ensures that the risk of failure due to delamination from the substrate is minimised. The reproducibility in adhesion over a wide range of substrates is a key driver to make WBCA-1 systems the first choice for primer applications.

## Perfect foundation for multi-coat applications

It can be concluded by the previous section that WBCA-1 provides excellent adhesion to the substrate. The other key requirement for a primer system is to provide a surface which can readily be overcoated with a further protective or aesthetic topcoat. Many coating applications consist of a number of layers to increase the protective properties and also to provide a highly decorative system. The re-coat window or recoatability of a coating after applying the initial layer is defined as the time within which a second coating can be applied to result in good adhesion. WBCA-1 based systems exhibit excellent recoatability with the surface presented, offering the ability to recoat immediately or after several months with epoxy, polyurethane or other coating technologies. The intercoat adhesion data clearly demonstrates that there is no intercoat adhesion failure when overcoating the WBCA-1 primer with a further coating of a WBCA-1 system.

A primer system based on WBCA-1 curing agent will be touch dry after 3-5 hours and can be overcoated with the following topcoat or self-levelling flooring system. Also the system is not susceptible to the formation of carbamation. As a result intercoat adhesion is not adversely affected due to application at low temperature or high humidity within the specified conditions.

**Table 2. Intercoat adhesion of commonly used epoxy primer systems**

| Primer and Coating Curing agent technology | After 1 day | After 3 days | After 1 month |
|---|---|---|---|
| WBCA-1 | Cohesive failure | Cohesive failure | Cohesive failure |
| Solvent free Cycloaliphatic | Cohesive failure | Partial intercoat failure | Intercoat failure |
| Solventborne polyamide | Cohesive failure | Partial intercoat failure | Intercoat failure |

## Decorative and protective high film build applications

For high traffic areas or those which require long term protection a coating system will only offer protection for a limited time without ongoing maintenance. High film build systems offer a significant level of protection to the floor which will reduce the maintenance requirements and ensure the longevity of the concrete substrate. A further waterborne system, WBCA-2 [10], has been developed which is based on similar technology to WBCA-1, but unlike WBCA-1 it is designed to be used in high film build applications such as self levelling floors. WBCA-2 enables highly protective flooring systems with the ability to comply with emerging EU regulations for the protection of inhabitants against hazardous emissions from building materials.

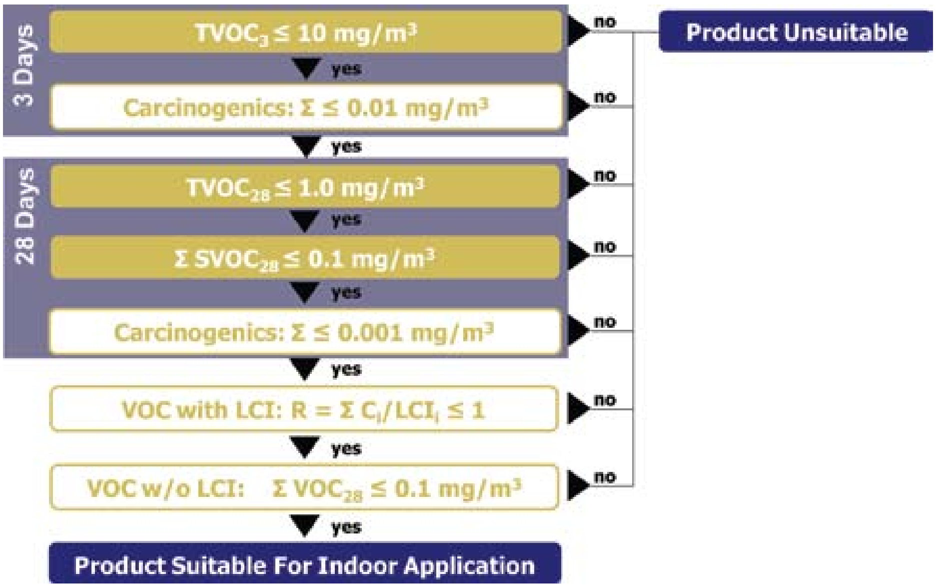
## Path to ensuring emmission compliant flooring systems

Evaluation of the exposure consequences from VOC emissions of cured flooring products to inhabitants and employees can be viewed as a three stage process. In the first stage a certain test method for evaluation of floor specimens is selected that defines preparation conditions and conditions during testing. Using this method, emission components are analyzed and characterised. The floor specimen is found suitable when the data generated meets the requirements as set forth by an accepted interpretation scheme. International technical work to understand critical test parameters and round robin testing between laboratories, led to the introduction of EN-ISO 16000 for the assessment of accumulated emissions from construction products. In this standard, cured floor specimens of 1 m2 applied on a substrate are evaluated for emissions up to 28 days at ambient conditions using a so called emission chamber. The chamber method using a floor specimen applied onto a substrate is generally accepted to offer best comparison with a real-life situation.

Further, for the evaluation of emission components, ECA Report 18 defines the concept of "lowest concentration of interest (LCI)". LCI is defined as a critical level of emission of a single component reported in µg/m3, below which a healthy indoor air quality for inhabitants and users during long-term continuous use is established. LCI values have been determined for many chemical substances [11]. Based on these values, the German AgBB committee [12] has proposed an interpretation scheme as outlined in Figure 2. This scheme validates the accumulated emission products at 3, 7 and 28 days after applying the flooring product [13]. EN-ISO 16000 divides emissions in subclasses with the following definitions:

- VOC:- Volatile Organic Component ranging between C6-C16
- TVOC:- Total VOC, accumulated VOC of products ≥ 5 µg/m3 ranging between C6-C16
- SVOC:- Slow-Volatile Organic Component > C16-C22
- ΣSVOC:- Total SVOC, accumulated SVOC of products ≥ 5 µg/m3 with > C16-C22

***Figure 2. AgBB evaluation scheme [13]***




The first measurement of the flooring sample is taken at three days after application and curing at 23°C and 50% relative humidity (RH). The emission limits are met when TVOC3 ≤ 10 mg/m³ and category 1 and 2 carcinogenic substances [14] are less than 0.01 mg/m3. When the emissions are less than 50% of the criteria, a second measurement after 7 days may be considered. If this measurement demonstrates less than 50% of the 28- day emission requirements, the floor specimen passes the emission testing. The 28 days measurement, however, requires the flooring product to comply with additional requirements, which each have more stringent limits than the 3 days data point. In the following order the 28 days requirements are: TVOC28 ≤ 1.0 mg/m³; ΣSVOC28 ≤ 0.1 mg/m³; carcinogenic substances [14] ≤ 0.001 mg/m³; substances with reported LCI value, R = Σ (Ci/LCIi) ≤ 1; while substances without any known LCI value need to demonstrate an accumulated VOC28 ≤ 0.1 mg/m³. In general, flooring products with low emissions find their application in the electronics industry where this feature is paramount in the manufacture of high quality electronic components. More specifically, flooring products that meet above AgBB requirements are suitable for use in the institutional and domestic flooring markets. Examples of these include schools, hospitals and nursing homes where inhabitants and users experience either prolonged exposure to flooring emissions or simply require additional care.

# Meeting the emission targets with WBCA-2 flooring

High film build floor systems offer a high level of protection to the concrete substrate. Flooring systems based on WBCA-2 are low odour and can be formulated free of VOCs as defined by the deco paint directive. The application of coatings in confined spaces limits the use of solvents and other volatiles, due to odour and regulatory constraints. This is equally important for sensitive application areas such as schools, offices or hospitals which can stay occupied during application.

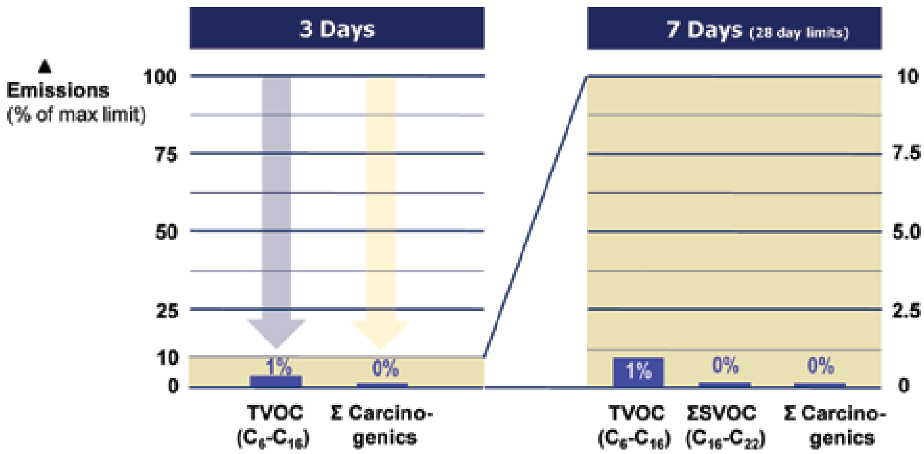
## Table 3. WBCA-2 Self leveling floor formulation

| | Self-Levelling Floor – 3K |
|---|---|
| ***A-Component*** | |
| 1. WBCA-2 | 10.00 |
| 2. Defoamer | 0.70 |
| 3. Pigment TiO2 | 3.70 |
| 4. Thixotropic Agent | 0.07 |
| 5. Water | 10.53 |
| | ***25.00*** |
| ***B-Component*** | |
| 6. Epoxy resin | **9.00** |
| ***C-Component*** | |
| 7. Fine Quartz Powder | 12.00 |
| 8. Quartz Powder | 28.00 |
| 9. Quartz Sand (0.1-0.3) | 35.00 |
| | ***75.00*** |
| **Total** | **109.00** |

As discussed previously, increasingly stringent regulations will further limit emissions from flooring systems during the lifetime of the coating. Conventional epoxy flooring products are frequently formulated with non-reactive components, such as benzyl alcohol, which has resulted in substantial emission levels above the proposed limits [15]. Self levelling coatings based on WBCA-2 are fully reactive and contain no plasticisers or solvents and therefore offer a compliant system. The WBCA-2 self levelling flooring formulation, as described in Table 2, has been evaluated for emission levels according to the German AgBB Scheme (Figure 2) for the evaluation of emissions from building products on a 2.5 mm floor applied on concrete. The results are shown in Figure 3.

After 3 days cure of the floor specimen at ambient temperature and 50% relative humidity (RH), a first specimen is analyzed for emission products. Figure 3 showed only 1% emission of VOC (C6-C16) components of the maximum norm and no detection of any carcinogenic substances. As a result of this extremely low emission, a second emission determination was taken after 7 days cure instead of the required 28 days. It should be noted that the maximum allowed emission limits after 28 day are much more stringent than those at 3 days because only 10% of the 3 day emissions are allowed. Despite this, emission levels at 7 days cure were found at only 10% of the 28 day limits (or 1% of the original limit set for 3 days). In addition, the R-value of components with a reported LCI was determined at less than 35% of the maximum allowable value at 28 days. Also the accumulated VOC (ΣVOC28) of components without a reported LCI value was extremely low, ie 5% of the 28 day maximum. These results clearly demonstrate that WBCA-2 self levelling formulation exceeds the AgBB criteria and can be categorized as a low emission flooring system. The data demonstrates that the system will meet the stringent future regulations in Europe and will have low emissions ideal for applications in the electronics industry or where low odour and tainting is of importance.

## Figure 3. Emission results of self-levelling floor based on Anquamine 731



## The ideal route to highly decorative and functional flooring systmens

Self levelling coatings based on WBCA-2 curing agent provide a desirable satin/matt finish to lessen the visibility of floor defects and reduce scratch sensitivity. However, the surface is very adaptable and can be modified to produce highly decorative surface appearances. Due to the inherent good overcoatability the self levelling floor can be readily coated with a transparent sealer or topcoat to produce a high gloss or decorative finish with improved chemical resistance and cleanability [16,17]. The surface can be easily modified by broadcasting sand or pigment effects and then sealing with a transparent topcoat such as industrial two component polyurethane coatings, waterborne polyurethane / acrylic hybrid dispersions or a two component waterborne epoxy system to offer highly decorative or non-slip flooring.

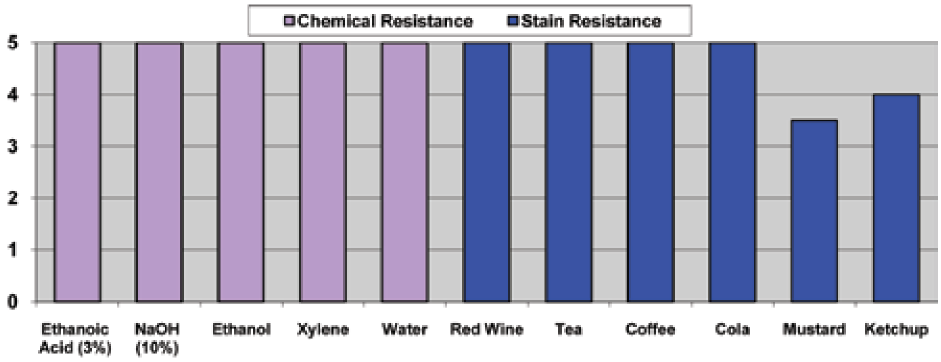
The WBCA-2 self levelling system also offers a high level of protection to the substrate, protecting it from abrasion, impact and chemical spill. Commonly applied concrete such as C25/30 offers a standard level of performance which is acceptable general purpose use. Such concretes will require a protective coating in order to enable a wider variety of uses such as forklift traffic and chemical exposure. Table 3 shows the physical properties of a self levelling system based on WBCA-2 curing agent compared to the typical properties of standard C25/30 concrete.

## Protection against chemical spills

Self levelling formulations based on WBCA-2 offer excellent resistance to a variety of chemicals. The resistance to some commonly used chemicals and staining foodstuffs is listed below in Figure 2, which demonstrates that for accidental spills and exposure WBCA-2 based systems will give very good protection of the concrete and can be cleaned without damage. In the figure a value of 5 indicates that there has been no damage or staining to the surface of the self levelling flooring with a value of 0 indicating that the flooring has been destroyed or heavily stained.

Protection against chemical spills is a key requirement for many industrial flooring applications and WBCA-2 based systems offer the required protection for most applications to ensure that the service time of the floor is increased with a cost-effective solution.

### Figure 4.Chemical and Stain resistance of WBCA-2 self leveling floor system.




### Table 4. Comparison of Physical Properties of Concrete and WBCA-2 based flooring system

| Physical Properties | Standard Concrete C25/30(A) | WBCA-2 |
|---|---|---|
| Surface Appearance | - | Satin / Matt |
| Compressive Strength (28 days) | 25-30 MPa | 40 MPa |
| Compressive Modulus (28 days) | 30,000 MPa | 750 MPa |
| Water Vapour Transmission (μ) (B) | 70-100 | 500-1,000 |
| Adhesion to Concrete | – | 4.5 MPa |
| Adhesion to Damp Concrete | – | 4.5 MPa |
| Impact Resistance | <25 kg.cm | 180-200 kg.cm |
| Abrasion Resistance (Taber CS17) | – | 300mg |
| Plasticiser Free | – | Yes |

(A) C25/30 acc. to EN1045-2001

(B) μ indicates moisture resistance of specimen relative to moisture resistance of motionless layer of air of the same thickness and temperature (μ ≡ 1)

In addition, this system provides high resistance to impact, e.g. from falling heavy objects. Upon impact a ‘dent’ but no cracking will occur so that concrete will be further protected without extensive repair works.

## Time is money

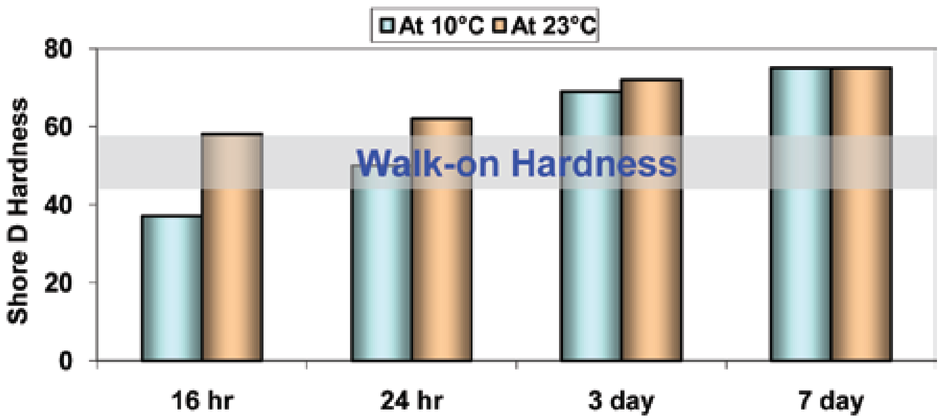
The self levelling flooring system based on WBCA-2, as described earlier, offers rapid property development allowing for a quick return to service. The fast property development is demonstrated at 23°C and 10°C indicating that even at low temperatures the system will produce a walk-on hardness after 24 hours. The system will withstand light traffic after limited cure time allowing for the floor to be back in service after application or overcoated with a further decorative surface finish much quicker than competitive technologies. This has the advantage of reducing the time a floor will be out of service which has economic and logistical advantages.

## Conclusions

In conclusion, WBCA-1 and WBCA-2 provide a comprehensive waterborne system with significant technical advantages over competitive technologies to provide high aesthetics and durable protection of concrete. Increased environmental awareness in society and industry has turned the spotlight on “green” technologies that meet the safety requirements both during the construction stage and during the lifetime of the building in service. Both WBCA-1 and WBCA-2 can be formulated without any solvent to result zero volatile organic components.

In addition, WBCA-2 based flooring systems have been demonstrated to comply with emerging EU emissions regulation as set forth by the German AgBB protocol. Test data reported here highlights that a flooring system based on WBCA-2 has less than 5% of the required emission limits (TVOC and ΣSVOC). In particular WBCA-2 has applicability in the institutional and domestic flooring markets where continuous exposure to flooring emissions are present. Another flooring application focused on low emissions is the electronics industry. Here, the requirement for low emissions is paramount enabling the manufacture of high quality electronic components. Finally technology discussed here has potential application in the industrial flooring sector, which ultimately may also move towards low emission requirements. Given this, waterborne epoxies will continue to be the technology of choice for high performance flooring systems for future applications.

### *Figure 5. Shore D Hardness Development as a Function of Time of Cure for WBCA-2 Self Levelling Formulation*




## References


1 See for example: Anquamine® 721 curing agent, technical datasheet, Air Products and Chemicals, Inc.
2 Council Directive 89/106/EEC of December 21 1988 on the approximation of laws, regulations and administrative provisions of the Member States relating to construction products, OJ L 40, 11 February 1989; often referred to as “Construction Products Directive (abbrev. CPD)”
3 Mandate M/366 “Development of horizontal standardized assessment methods for harmonized approaches relating to dangerous substances under the Construction Products Directive (CPD)”, EU Commission, DG Enterprice, Brussels, 19 March 2005
4 European Collaborative Action “Indoor Air Quality and Its Impact On Man”, Evaluation of VOC emissions from building products; solid flooring materials (Report no. 18), EUR17334EN, European Commission, Joint Research Centre, Environment Institute, 1997;
5 European Collaborative Action “Urban Air, Indoor Environment and Human Exposure”, Harmonisation of indoor material emissions labeling systems in the EU; inventory of existing schemes (Report no. 24), EUR21891EN, European Commission, Joint Research Centre, Institute for Health and Consumer Protection, 2005;
6 C. May and Y. Tanaka, “Epoxy Resins”, Marcel Dekker Inc (New York), 1973, Chapter 6 “Epoxy resin adhesives” by A. Lewis and R. Saxon
7 J. Baghdachi, “Adhesion aspects of polymeric coatings”, Fed. Of Soc. for Coatings Technology (Blue Bell, USA), 1996, Chapter IV-VII
8 C. Hare, “Protective Coatings, Fundamentals of chemistry and Composition”, Technology Publishing Co. (Pittsburg), 1994, Chapter 2
9 P. Oldring (Ed.), “Waterborne and solvent based epoxies and their end user applications”, SITA Technology Ltd (London), 1996, Chapter 10 (part VII)
10 Anquamine® 731 curing agent, technical datasheet, Air Products and Chemicals, Inc.
11 See for example for a recent list of substance LCI values: Ausschuss zur Gesundheitlichen Bewertung von Bauprodukten (AgBB), “Bewertungsschema für VOC aus Bauprodukten”, Part 3, 1 March 2008
12 AgBB - Ausschuss zur Gesundheitlichen Bewertung von Bauprodukten
13 id 11, Part 1 and 2
14 definitions per EU Dir 67/548/EEG
15 M. Glöckner, Statement der Deutschen Bauchemie; presented at: “Zweite Fachgespräch zur Vorgehensweise bei der gesundheitlichen Bewertung der Emissionen von flüchtigen organischen Verbindungen (VOC) aus Bauprodukten”, DIBt, Berlin, 25 November 2004
16 T.J. Lim, Ernest C. Galgoci, Frederick H. Walker, and Kenneth A. Yoxheimer, ˝Meeting the Regulatory Challenge: Marrying Novel Surfactant Technology with Waterborne Hybrid Resin Technology for Unique High-Performance Solutions to Low VOC Coatings Requirements˝, European Coatings Journal, May 2005, p24-30
17 Anquawhite® 100 curing agent, technical datasheet, Air Products and Chemicals, Inc.


**tell me more**
**www.airproducts.com**

**Air Products plc,** Hersham Place Technology Park, Molesey Road, Hersham, Walton-on-Thames, Surrey KT12 4RZ