Survey on alternatives for in-can preservatives for varnishes, paints and adhesives

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Contents

Studie zu Alternativen für Topfkonservierungsmittel für Farben, Lacke und Klebstoffe

Kurzreferat

Wasserbasierte Lacke, Farben und Klebstoffe benötigen Topfkonservierungsmittel. Dies gilt für die Rohmaterialien – Polymerdispersionen – ebenso wie für die Endprodukte, um die erforderliche Haltbarkeitsdauer zu gewährleisten. Isothiazolinone und Formaldehydabspalter sind aktuell die wichtigsten Wirkstoffe für diesen Zweck. Erstere können allergische Hautreaktionen verursachen, während letztere als Karzinogene der Kategorie 1B eingestuft und deshalb zu ersetzen sind. In dieser Studie wurde untersucht, ob alternative Substanzen mit geringerem Risiko bei vergleichbarer Wirksamkeit verfügbar sind. Dazu wurden Literaturstudien und Experteninterviews mit Vertreterinnen und Vertretern der betroffenen Branchen sowie der gesetzlichen Unfallversicherer durchgeführt.

Die Produktion von Lacken, Farben und Klebstoffen erfolgt sowohl in kleinen bis mittleren Manufakturen als auch im großindustriellen Maßstab. Dabei ist das Expositionspotential bei Kleinbetrieben tendenziell höher als bei Großbetrieben, weil die großmaßstäbliche Produktion zumeist im geschlossenen System erfolgt. Produktanwender mit potenzieller Exposition zu den konservierten Farben und Klebstoffen finden sich in Branchen wie dem Bauhandwerk, Möbelbau, Verpackungs- und Druckindustrie, aber auch bei Kunstmalern. Aus den Interviews mit Experten entlang der gesamten Produktions- und Anwendungslinie ergaben sich keine Hinweise auf ein besonders hohes Gesundheitsrisiko durch Topfkonservierer.

Infolge früherer und aktueller Regulierungsaktivitäten hat sich die Verfügbarkeit von Wirkstoffen für eine wirksame Topfkonservierung wasserbasierter Beschichtungen und Klebstoffe reduziert. Es gibt bisher nur wenige Alternativen, die vollständig auf den Einsatz von Topfkonservierern verzichten und die möglichen Alternativen haben oft negative Nebeneffekte (wie z.B. Silikatfarben mit einem hohen pH-Wert von 11,5). Trockene Farben, die bereits vor rund 20 Jahren allerdings ohne großen Erfolg auf den Markt gebracht worden waren, wurden vor kurzem wieder eingeführt.

Als Hauptgrund für den Mangel an Forschungsaktivitäten bezüglich neuer Wirkstoffe wurde das anspruchsvolle und langwierige Genehmigungsverfahren gemäß Biozid-Verordnung (EU) Nr: 528/2012 in Verbindung mit dem geringen Marktvolumen von Bioziden genannt. Alle Optionen, Wirkstoffe aus anderen Bereichen (Pestizide oder andere Produktarten gemäß Biozid-Verordnung) zu übertragen, wurden entweder bereits ausgeschöpft oder konnten von vorneherein als nicht zielführend ausgeschlossen werden. Aus diesen Gründen ist die Produktinnovation hauptsächlich auf neue Kombinationen bereits bekannter Wirkstoffe beschränkt.

Auch die meisten Maßnahmen für eine verbesserte Prozesshygiene wurden bereits umgesetzt. Einige Hersteller sehen jedoch noch ein gewisses Potenzial, ihre Anlagen und Prozesse zu optimieren. Ein vollständiger Verzicht auf Konservierung des Endproduktes ist jedoch auch dann nicht möglich, da ansonsten die erforderlichen Haltbarkeitszeiten im Handel und beim Endverbraucher nicht gewährleistet werden können.

Schlagwörter:

Topfkonservierer, Isothiazolinone, Biozidprodukte, Biozid-Verordnung, Alternativen, wasserbasierte Farben, wasserbasierte Klebstoffe, Polymerdispersionen

Survey on alternatives for in-can preservatives for varnishes, paints and adhesives

Abstract

Water-based varnishes, paints and adhesives require conservation with in-can preservatives, both, for their raw materials —polymer dispersions — and the end products in order to warrant the necessary shelf life. Isothiazolinones and formaldehyde donors are currently the most relevant active substances for this purpose. The former can induce allergical skin reactions while the latter are being classified as carcinogen of category 1B and therefore under obligation to be phased out in the future. In this study it was examined if there are feasible alternative substances or procedures with comparable effectiveness for in-can preservation, but which have lower risks. Current literature was investigated and expert interviews were conducted with representatives from concerned industry branches and from workers' compensation boards.

Production facilities for varnishes, paints and adhesives range from small or medium scale manufacturers to large scale industrial production with the former having higher potential workplace exposure and the latter mainly operated as closed systems. Product application occurs in diverse branches like building trade, furniture construction, packaging industry, printing industry or artisan painters with potential exposure to the preserved coatings or adhesives. In expert interviews, there were no substantial hints to an especially high occupational risk resulting from in-can preservatives in any step of production and/or end use.

As a consequence of previous and ongoing regulation, potential options for in-can preservation of water-based coatings and adhesives in general are narrowed. Options to completely avoid in-can preservatives are scarce and often combined with adverse side-effects (e.g., silicate paints with pH 11.5). Dry paints, which had been on the market some twenty years ago, but were not successful, have been reintroduced into the market just recently, but their economic success remains to be seen.

As major cause for the lack of research on new active agents the experts named the demanding and protracted approval process under the Biocidal Products Regulation (BPR) (EC) No. 528/2012 as the relation of R&D investments to market value is very unfavourable for biocides in general and in-can preservatives in particular. All options to transfer active substances from other sectors, e.g. pesticides or from other product types according to BPR have either been exhausted or were not feasible in the first place. Product innovation therefore focuses mainly on new combinations of existing agents.

Most measures for an improved process hygiene have already been implemented. Some manufacturers are still seeing some potential to optimise their facilities and processes, but this does not allow the avoidance of preservation measures in order to achieve the necessary shelf life of the end products.

Key words:

In-can preservatives, isothiazolinones, Biocidal Product Regulation (BPR), biocidal products, alternatives, water-based colours, water-based adhesives, polymer dispersions

1 Introduction

According to the Biocidal Products Regulation[1] (BPR) active substances for the preservation of water-based varnishes, colours and adhesives belong to the category of product-type 6 (PT 6: In-can preservatives). Primarily isothiazolinones are used for this purpose as they can control a large spectrum of bacteria as well as fungi. But there are also undesirable effects as these substances can induce allergical skin reactions. Formaldehyde donors show comparable efficacy but are classified as carcinogens of category 1B and therefore must be phased out in the future. The list of old active substances used for in-can preservation in the review programme[2] for the systematic examination of all existing active substances contained in biocidal products comprises 52 substances. From those substances 11 have been approved, 3 have not been approved and remaining substances being reviewed can be used in the meantime until a decision for approval is made.
There are ongoing procedures for the classification and labelling of in-can preservatives as skin sensitising according to appendix VI of CLP regulation. Some have been finished. For 5-Chloro-2-methyl-4-isothiazoline-3-one/2-Methylisothiazol- 3(2H)-one (CMIT/MIT, CAS No. 55965-84-9) there is already a proposition (Skin Sens 1A, H317) while MIT (CAS No. 2682-20-4) has already been classified as Skin Sens 1A, H317. It is to be expected that this will hold for other isothiazolinones as well.
Options to completely avoid in-can preservatives are scarce and in general combined with adverse side-effects. For example, there are silicate paints available which avoid use of biocides but they can only be used on mineral surfaces. Therefore, their use is technically restricted. Due to their high pH (11.5) they can cause skin or eye irritations.
Regarding occupational health and safety, the use of paints and varnishes in e.g. roller or spraying application increases the possibility of exposure of the professional user. Especially, sensitising substances must be regarded as particularly critical, as they can cause allergic reactions. These can occur regardless of concentration after sensitisation by frequent or high exposure has taken place.
In order to protect professional users against exposure to in-can preservatives for paints, varnishes and adhesives, which are hazardous substances, this project wants to investigate if there are feasible alternative substances or procedures with comparable effectiveness for in-can preservation, but which are less hazardous.

Therefore, in April 2019 chromgruen has been assigned by the Federal Institute for Occupational Safety and Health (BAuA) to carry out this survey. The project is structured into two work packages:

1. Description of the current situation with regard to currently used biocidal products, their application fields, technical requirements as well as hazards in the workplace.
2. Research on new active components and their advantages and/or drawbacks esp. in regard to hazards in the workplace, technical conditions, and costs and compilation of information on techniques to reduce bacterial loads in the production process

The project lasted from May 2019 to March 2020.

[1] Regulation (EU) No 528/2012 of the European Parliament and of the Council of 22 May 2012 concerning the making available on the market and use of biocidal products.
[2] DELEGATED REGULATION (EU) No 1062/2014.

2 Methodical approach

2.1 Literature research

The following databases were researched with regard to the project objectives: PubMed, Medline, EmeraldInsight, GreenFile, OpenDissertations, ScienceDirect, SpringerLink, and Wiley Online Library. Search terms are listed in Table 2.1.

Table 2.1 Search terms for literature research

German search terms	English search terms
Topfkonservier*	in-can preservative*
Dispersionsfarbe + Biozid	preservatives for products during storage
Dispersionsfarbe + Konservier*	coating + preservative
Farbe + Biozid	paint + preservative
Farbe + Konservier*	glue + preservative
Lack + Biozid	adhesive + preservative
Lack + Konservier*	coating + biocide
Klebstoff + Biozid	glue + biocide
Klebstoff + Konservier*	adhesive + biocide
Isothiazolinon	paint + biocide
	coating + storage
	paint + storage
	glue + storage
	adhesive + storage
	storage + biocide
	isothiazolinone

Search in Medline gave no results, while search in EmeraldInsight gave 133 results only for search term “preservatives for products during storage”. Results for the other databases are summarised in Annexes 1 and 2. The following diagrams visualise these results.

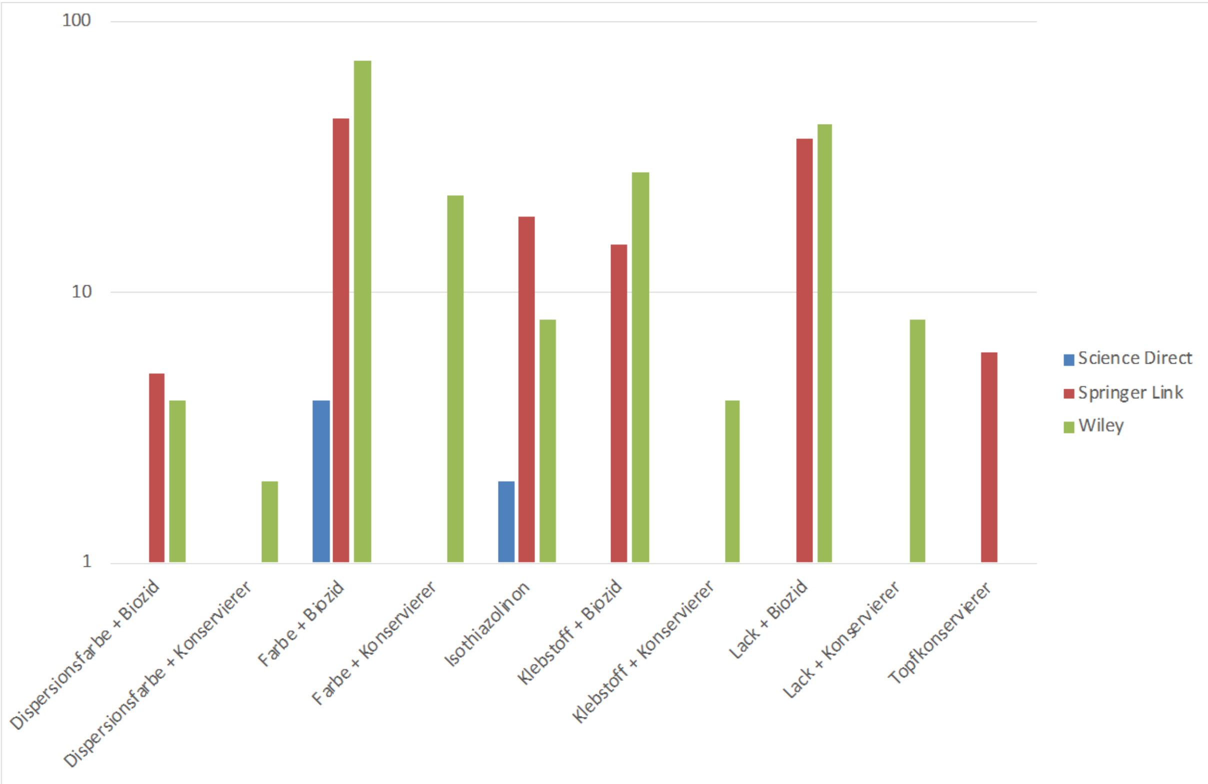

Fig. 2.1 Results for german search terms (logarithmic scale)

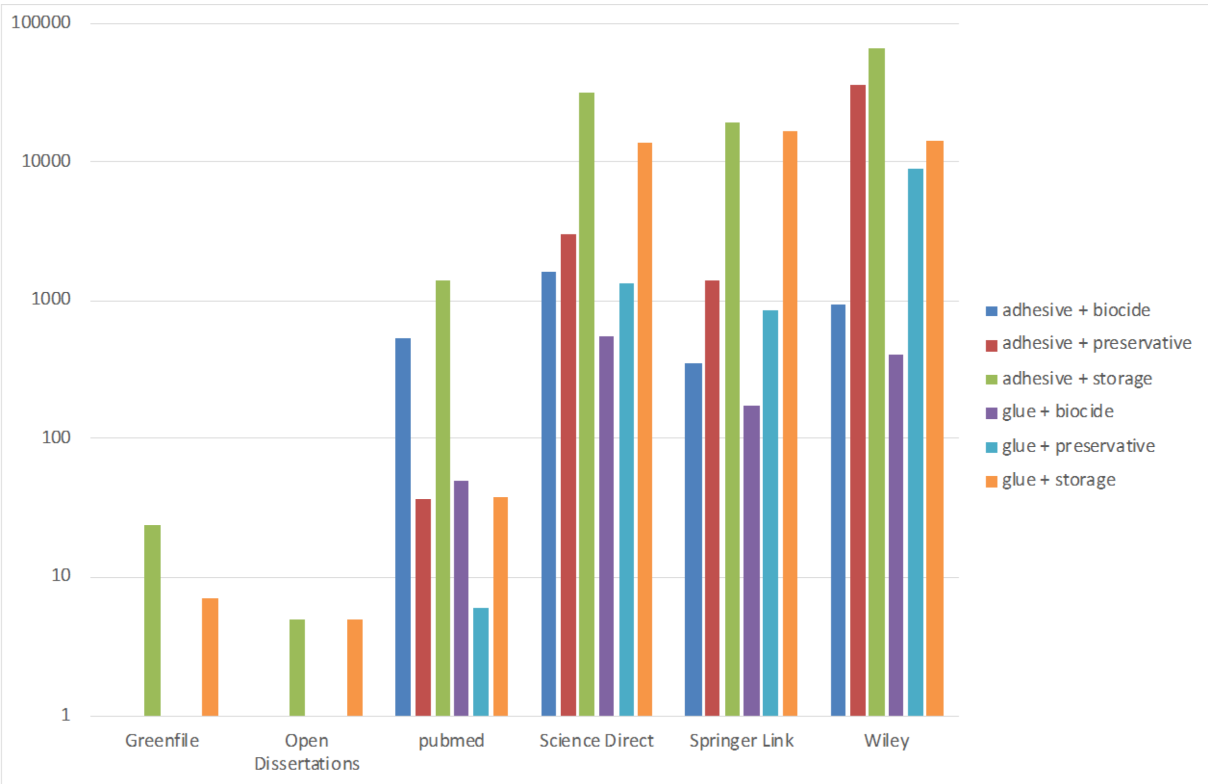

Fig. 2.2 Results for adhesives-related english search terms (logarithmic scale)

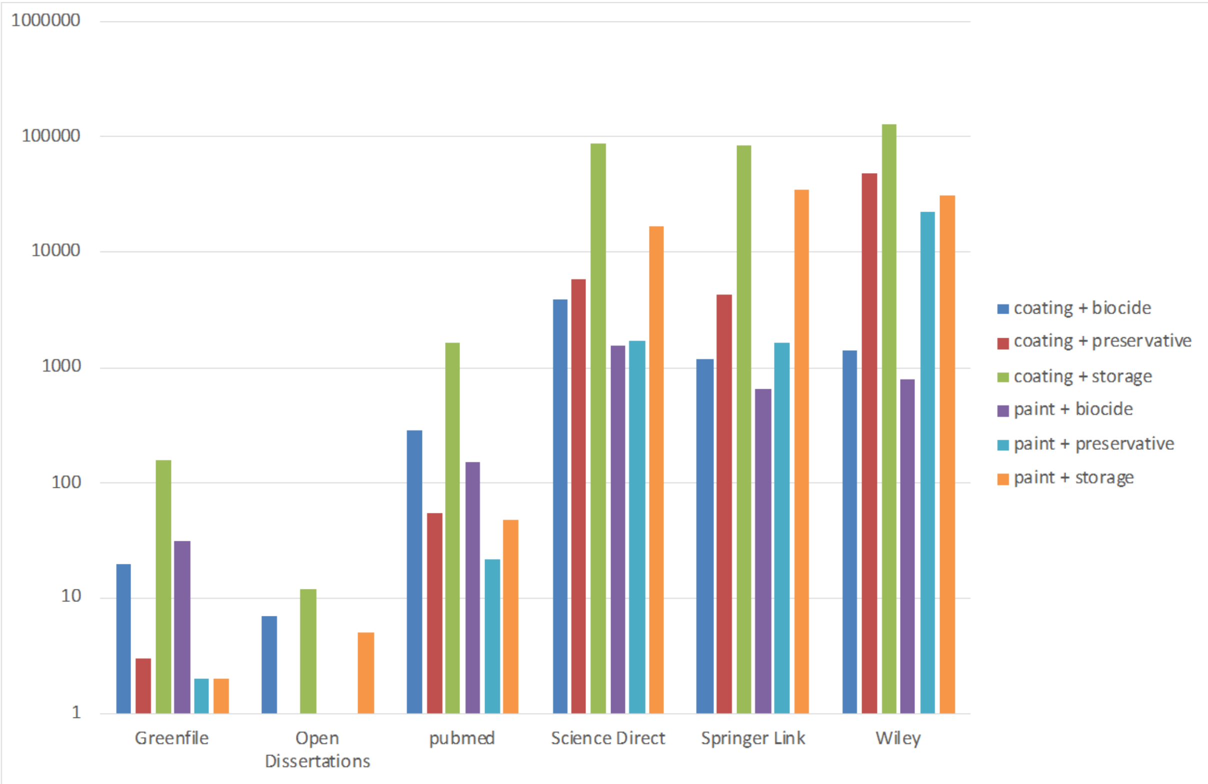

Fig. 2.3 Results for paints-related english search terms (logarithmic scale)

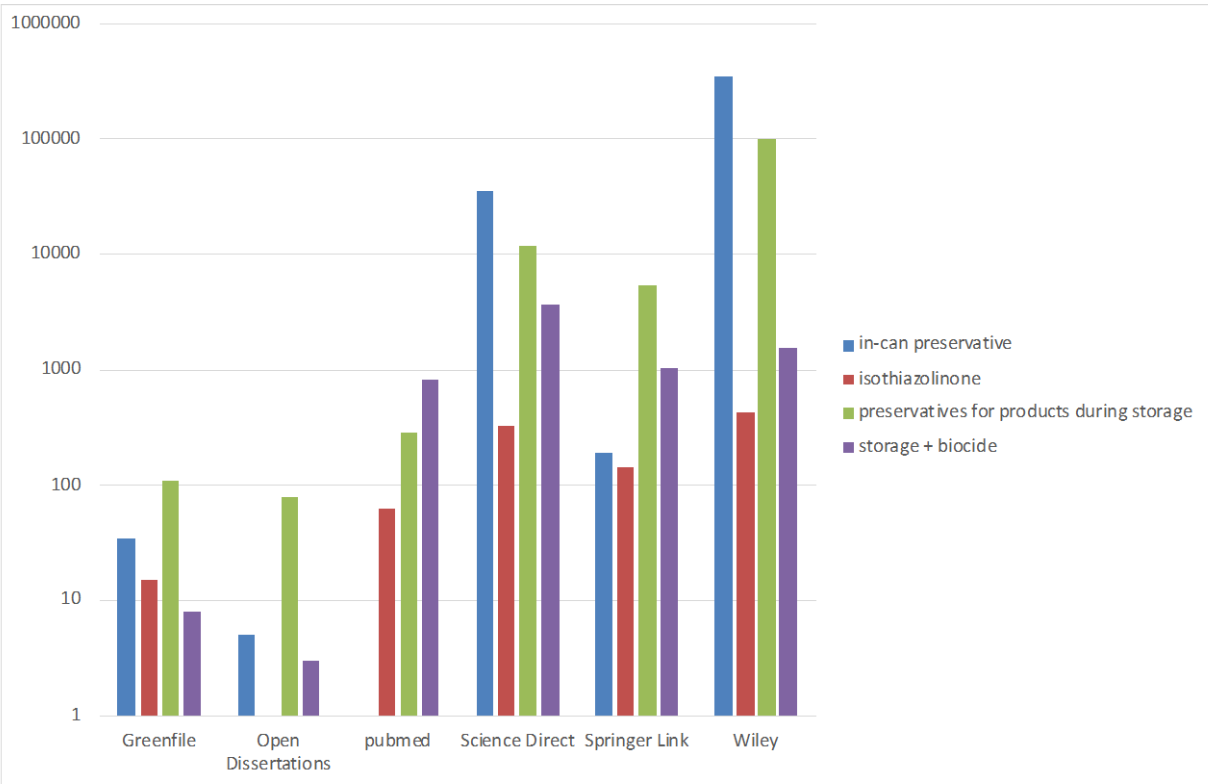

Fig. 2.4 Results for generic english search terms (logarithmic scale)

While this research in principle resulted in large numbers of results (as depicted above) a more detailed analysis showed that most articles were not relevant for this study. Refining rather generic search terms like, e.g., “paint + storage” by adding “biocide”

significantly reduced the result sets on average by more than 90 %. But still many of the remaining articles bore no relevance as, e.g., they dealt with wood protection, food safety, or cosmetics as well as with medical subjects in general. Additionally, there were quite a few documents that dealt with allergological issues regarding isothiazolinones. As this had been a precondition for this project it was also not seen as relevant information to be examined.
Therefore, and with regard to the project timeframe and its focus on recent industry practices in contrast to basic research activities it was abstained from an extensive and detailed literature analysis in favour of more expert interviews.

2.2 Interviews

In order to gain recent insights personal and/or telephone interviews with experts in the field were to be carried out. Relevant interviewees are especially representatives of institutions and companies who are dealing with the production of water-based paints, varnishes or adhesives or who are dealing with the production of in-can preservatives (active substances as well as biocidal products of PT 6). Another relevant group are experts in the field of occupational safety and health in the application of water-based paints, varnishes or adhesives.
Some potential interview partners had already been identified in the application phase for this project:

- Manufacturers of in-can preservatives
- Manufacturers of biocidal free paints
- Other institutions like, e.g.,
    - Deutsches Institut für Bautechnik – AöR
    - BG BAU – Berufsgenossenschaft der Bauwirtschaft
    - Bundesverband Farbe Gestaltung Bautenschutz
    - German Association of Chemical Industry
    - German Association of paints and varnishes industry
    - RAL – Deutsches Institut für Gütesicherung und Kennzeichnung e. V.
    - Europäische Gesellschaft für gesundes Bauen und Innenraumhygiene.

Additionally, based on the supplier database "wer liefert was" about 280 suppliers of paints, varnishes, adhesives or biocides as well as other institutions were contacted via eMail (see Table 2.2).

Table 2.2 Groups and group sizes to be contacted for interviews

Group	**No. of contacts**
Producers of biocidal products	10
Producers of varnishes	82
Producers of adhesives	178
Other institutions	10
Sum	280

There was only a very small return. Most answers (15) resulted from companies who claimed not to use in-can preservatives, because they were only producing solvent-based products (paints, varnishes, adhesives).

Positive feedback from the German association of paints and varnishes industry (VdL), the German association of chemical industry (VCI), the German Adhesives Association (IVK e.V.), Auro AG ("ecological paints, wood care and cleaning products") and the workers' compensation board of construction industry (BG BAU) led to personal interviews. The German association of paints and varnishes industry (VdL) provided direct contact information of experts from industry who had agreed to an interview. Therefore, most of the interviews with experts from this branch resulted from these contacts. Identified persons/institutions were contacted and interviewed with regard to their specific role. For this purpose, interview guidelines were prepared for each group/aspect.
In this project 14 interviews have been conducted. Interview partners are described in Table 2.3.

Table 2.3 List of interviews

No.	Description
1	Industry associations of paint producers and of chemical industry
2	Manufacturer of Biocidal Products
3	Manufacturer of printing paints
4	Manufacturer of building paints, also biocide free paints
5	Manufacturer of paints and adhesives based on natural substances
6	Seven Manufacturers of adhesives and polymer dispersions and German Adhesives Association (IVK)
7	Manufacturer of building paints
8	Manufacturer of polymer dispersions for paints and adhesives
9	Employers' liability insurance association of construction industry
10*	European Council of the Paint, Printing Ink and Artists‘ Colours Industry
11	Manufacturer of artists’ water-based colours
12**	Consultant of Coatings industry
13	Manufacturer of building paints, also biocide free paints
14**	Research institute

*: Brief telephone interview and provisioning of statistical data
**: e-mail correspondence

Additionally, feedback from three associations of workers' compensation boards of the German Statutory Accident Insurance and one industry association was received in writing.

3 In-can preservatives for water-based coatings and adhesives

3.1 Polymer dispersions as base material for water-based coatings and adhesives

Water-based polymer dispersions form the basis both for many water-based paints as well as for water-based adhesives. They are susceptible to microbial contamination. The following Table 3.1 shows the different susceptibilities of some polymer dispersion raw materials. Gillat (2005) describes the test procedure as follows: "*By adding various of these to water at in-use concentrations, followed by inoculation with a variety of bacteria, yeasts and moulds isolated from contaminated products, they were able to show that many surfactants, defoamers and other additives were highly susceptible.*"

Table 3.1 Susceptibility of polymer dispersion raw materials (Gillat, 2005)

		Susceptibility to:		
Raw materials	**Tested conc.**	**Bacteria**	**Yeasts**	**Moulds**
Surfactants/wetting agents				
Polyethoxyethanol	0.3%	−	−	−
Ethoxylated tetramethyl decinediol (30 moles)	0.3%	−	+	−
Ethoxylated tetramethyl decinediol (10 moles)	0.3%	−	+	−
Nonylphenoxypoly (ethyleneoxy) ethanol A	0.3%		−	−
Sodium salt of alkylaryl polyether sulphate	0.3%	−	−	−
Nonylphenoxypoly (ethyleneoxy) ethanol B	0.3%	−	−	−
Octylphenoxy polyethoxy ethanol	0.3%	−	+	−
Nonylphenoxypoly (ethyleneoxy) ethanol, wax	0.3%	−	−	−
Polyol emulsifier — liquid	0.3%	+	+	−
Polyol emulsifier — solid	0.3%	−	−	−
Defoamers				
Proprietary liquid defoamer A	0.07%	−	−	+
Speciality formulated defoamer	0.05%	−	+	+
Proprietary liquid defoamer B	0.05%	−	+	−
Proprietary liquid defoamer C	0.07%	−	+	+
Thickeners				
Hydroxyethyl cellulose thickener A	0.4%	+	+	−
Hydroxyethyl cellulose thickener B	0.16%	−	+	+
Hydroxyethyl cellulose thickener C	0.44%	+	+	−
Others				
Polyvinyl alcohol A	0.65%	+	+	+
Polyvinyl alcohol B	1.44%	+	+	+

The (intended) reduction of monomer concentrations due to their toxic properties in consequence increased the need for biocides.
Most of the bacteria, yeasts and moulds, which can be found in the environment are present in samples of polymer dispersions, as well as in formulated products containing them. Gillat (2005) cites a study by the „International Biodeterioration Research Group" (IBRG) in which the viability in polymer dispersions of 175 microbial species was evaluated. Summarised results are displayed in Table 3.2. It has to be noted that the utilised dispersions were not standardised, but these analyses later formed the basis of the IBRG testing methods for efficacy of biocidal active substances (as published on ibrg.org).

Table 3.2 Polymer Dispersion Organisms (IBRG study) – Gillat (2005)

Organism	**No. of species**	**Of which:**
Bacteria		
Pseudomonas	30	12 were Pseudomonas aeruginosa
		6 were Pseudomonas putida
		5 were Pseudomonas fluorescens
		5 were Pseudomonas stutzeri
Escherichia	11	All were Escherichia coli
Alcaligenes	11	6 were Alcaligenes faecalis
Proteus	9	6 were Proteus vulgaris
		2 were Proteus morganii
Flavobacterium	6	Various species
Klebsiella	5	3 were Klebsiella pneumoniae
Micrococcus	5	4 were Micrococcus luteus
Moulds:		
Aspergillus	10	5 were Aspergillus niger
		2 were Aspergillus oryzae
Geotrichum	7	5 were Geotrichum candidum
Penicillium	7	2 were Penicillium ochrochloron
Yeasts:		
Candida	7	3 were Candida albicans
		2 were Candida valida
Rhodotorula	4	2 were Rhodotorula glutinis
		2 were Rhodotorula rubra
Saccharomyces	2	both were Saccharomyces cerevisiae"

3.2 Coatings and paints

The demand for coatings and paints in Europe has increased by 30 % from 1995 to 2005 (see Table 3.3).

Table 3.3 World paints and coatings demand (metric tons) – (Ita, P., 2002, cited in Lindner, 2005)

	1995	**2000**	**2005 (estimated)**
North America	5,977,000	7,010,000	8,010,000
Western Europe	4,960,000	5,605,000	6,400,000
Japan	1,956,000	1,851,000	2,060,000
Asia Pacific (excl. Japan)	3,814,000	4,718,000	6,310,000
Rest of the World	4,023,000	4,416,000	5,520,000
World	20,730,000	23,600,000	28,300,000

For 2018, the following production figures regarding Germany have been published by the industry association of paint producers (Table 3.4).

Table 3.4 Production volumes (metric tons) in Germany (VDL, 2019)

Group	**Output 2018**
solvent based coatings	503,023
powder coatings	78,047
indoor water-based dispersion paints	556,124
façade water-based dispersion paints	136,626
water-based dispersion varnishes	137,578
silicate paints	64,931
sum total of water-based dispersions, stucco, water-based coatings	**1,472,854**
sum total coatings	**2,246,775**

With regard to application areas in Germany, 848,000 t are used in construction industry vis-à-vis 505,000 t used for industrial coatings and 257,000 t for printing paints (VDL 2018). Production volumes differentiated by base solvent media have developed as described in Table 3.5.

Table 3.5 Trends in paints and coatings production volumes (metric tons) in Germany (VDL 2019)

	Solvent-based Coatings	**Powder Coatings**	**Dispersion paints (indoor)**	**Dispersion paints (outdoor)**	**Dispersion varnish**
1995	523,805	52,936	472,592	154,157	32,375
2000	561,017	63,353	584,078	168,179	48,441
2005	530,648	65,410	631,999	168,728	90,269
2010	484,620	63,658	614,784	133,898	119,193
2015	476,102	74,158	586,861	152,372	130,452

This is visualised in Fig. 3.1 and Fig. 3.2 based on VdL (2019).

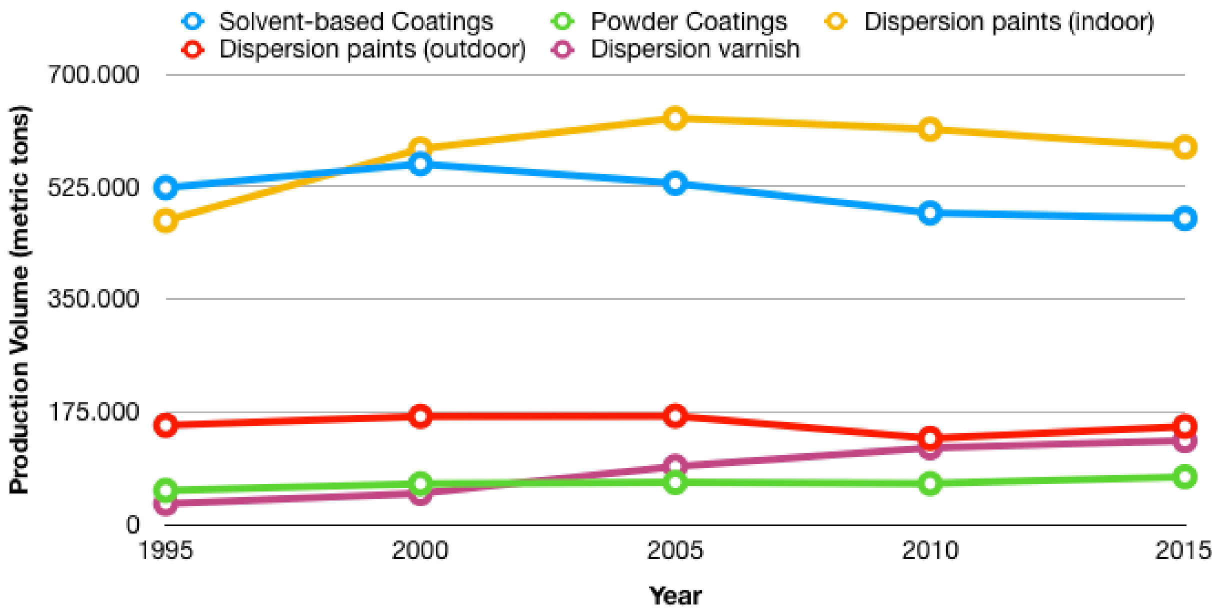

Fig. 3.1 Trends in paints and coatings production volumes (metric tons) in Germany

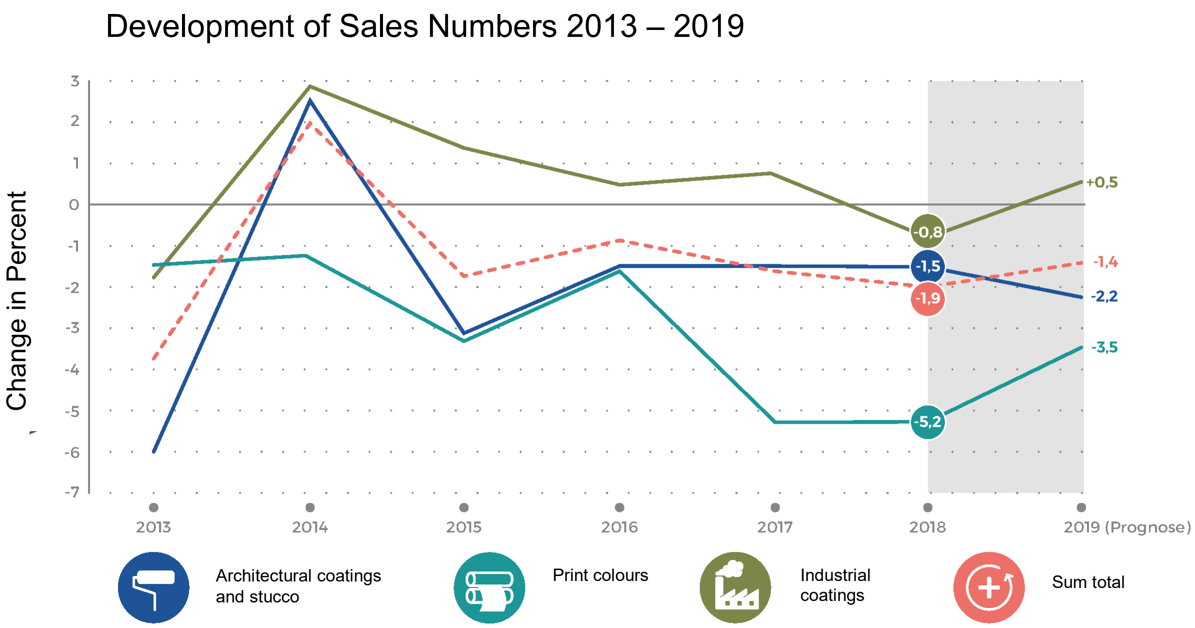

Fig. 3.2 Trends of sales volumes of paints, varnishes and printing inks, Germany 2013-2019 (VdL 2019)

Regulatory measures by the European Union to reduce the emission of volatile organic compounds (VOC) have led to a significant reduction of solvent contents in coatings. This trend started in the 1990s with the VOC Solvents Directive (1999/13/EC, European Union 1999). In 2004, the “(Deco)Paint directive” (2004/42/EC, European Union 2004) was published which amended the VOC directive. This directive regulates the emissions for specified paints and coatings. In its Annex II maximum VOC content limit values are defined for solvent as well as for water-based coatings in a stepwise approach with the first set of limits taking effect in 2007 and a stricter set of limits taking effect in 2010. Especially these regulatory changes but also the banning of certain toxic (heavy metal based) pigments led to a higher susceptibility to microbial attack and therefore to a higher demand for biocidal protection. The consequences of this development are described exemplarily for industrial coatings (Interview 12).

Water based coatings in general consist at least of the following ingredients: water, a polymer dispersion, pigments, fillers, rheology modifiers, and further additives.

3.2.1 Architectural coatings

According to Lindner (2005) the architectural coatings industry is the biggest market segment for biocides. He cites Kuropka (1999) who describes typical paint starter formulas for this type of application (Table 3.6).

Table 3.6 Typical starter formulas for architectural paints (Kuropka, 1999) — cited in Lindner 2005

	Proportion [%] in			
Ingredient	**interior paint**	**exterior paint**	**white enamel**	**Function**
Water	30	5 to 12	5	Diluent
Cellulose ether (HEC, MHEC, CMC)	0.3 to 0.6	0.15 to 0.25	0.1 to 0.25	Thickener
Polyphosphate	0.05 to 0.15	0.05 to 0.1	0	Co-dispersant
Polyacrylate	0.2 to 0.5	0.2 to 0.5	0.5 to 1	Dispersant
Ammonia (25%) or Alkali solution (10%)	0.2 to 0.5	0.2 to 0.5	0.2 to 1.5	pH-regulator
Titanium oxide	5 to 15 (Anastas/Rutile)	5 to 25 (Rutile)	15 to 25 (Rutile)	White pigment
Carbonate +Silicates	40 to 60	20 to 40	0	Extender
Polymer dispersion (50%)	8 to 18	20 to 40	50 to 70	Binder
Defoamer	0.3	0.3	0.3	Additive
Film forming agent/solvent	0 to 2	1 to 3	0 to 10	Coalescent
Acrylate/PU	0 to 0.5	0 to 0.5	1 to 4	Associate thickener
In-can preservative	0.25	0.2	0.25	In-can preservative
Film-preservative	0	0.1 to 1.5	0	Fungicide-algicide

Preservation is strongly influenced by the product composition. Factors, which influence the preservation are, e.g., pigment content (pigments are a significant cost factor), raw materials quality (e.g., type of thickeners or binders), especially the biodegradability of the used materials (Lindner 2005).

Urbańczyk et al. (2018), e.g., investigated the photo transformation of four commonly used biocides (carbendazim, diuron, octylisothiazolinone (OIT) and terbutryne) in four different paint formulations differing solely in pigments (red and black iron oxides, white titanium dioxide, and one pigment-free formulation). They state that for three of these biocides (diuron, OIT, terbutryne) degradation speed was highest in the pigment-free formulation with carbendazim displaying no degradation at all. On the other hand, degradation was found to be considerably lower in pigment-containing paints. The authors describe differing photo transformation product ratios of terbutryne and OIT depending on the pigments. Of course, photo transformation is of higher relevance for film preservatives (which form a different biocidal product type – PT 7), but the described findings in general underline the argument made above by Lindner (2005).

Regarding biodegradability Lindner (2005) states that in cheap ceiling paints, carboxymethyl cellulose (CMC) is used as a thickener and binder, which is easily degradable.

Another notable aspect is the presence of large surface materials like carbon black in solvent free tinting pastes, which are handled in tinting machines in retail stores. They are therefore under risk of fungal spoilage while the biocidal agents may be absorbed to the carbon surfaces and even destroyed by catalytic effects. Due to their diverging properties as well as their different 'shelve times' (in the tinting machines) each colour has to be treated separately. A similar problem can result in the case of industrial paints, because the time spent in the respective machine or tank has to be added to the in-can storage time. Lower preservation would therefore require shorter turnaround times.

3.2.2 Water-based industrial coatings

Regarding water-based industrial coatings two phases of introduction can be distinguished:

- The introduction of electrophoretic painting, anodic since 1964, cathodic since the early 1970s
  In the early stages electrodeposition paints did not need biocides due to relatively high solvent contents (3 to 6 %), and the presence of metal salts like zinc and strontium chromate in case of anodic processes, and lead salts in case of cathodic processes. Microbial contamination first became a problem with the introduction of two-component varnishes (dispersion – with solvent content below 2% – and pigment paste) and lead-free as well as organo-tin-free coating products.
- The use of water-based spray paints in the automotive industry in the 1980s
  Typical bath temperatures around 30°C provide optimal growth conditions for microorganisms. In case of water-based spray paints normally the varnish does not pose a problem with regard to microbial contamination as most products contain 5 to 20% of organic solvents (which is different from architectural coatings). In case of industrial wood coatings on the other hand solvent content of dispersions lies below three percent. Other problematic applications are the production of solvent-free acrylate and polyurethane dispersions. The production of demineralised water, which complements the immersion baths is another weak point with regard to microbial contamination. Moisturised varnishing booths (either for water-based varnishes or to ensure a uniform electrostatic application) are susceptible to microbial contamination as well.

3.2.3 Water-based artists' colours

The preservation of water-based artists' colours like acrylic paints or aquarelle colours form a special case (Interview 11). Storage life is warranted for three years but longer stability is expected by many clients. Variety of products is rather high with small production volumes. Turnover times are quite long, which poses a problem regarding regulatory changes.

3.3 Adhesives

In Germany, production of adhesives has grown from 815,000 t in 2008 to 955,000 t in 2018 according to German Adhesives Association (IVK 2019). Of these, 44% are water-based dispersions, 4 % based on natural polymers, 15 % are hotmelts, 6 % solvent-based and 31 % are described as "others". The three largest domestic sectors using water-based adhesives are paper/packaging industry (47%), construction (22%) and private households (11%) (see Fig. 3.3, IVK 2019).

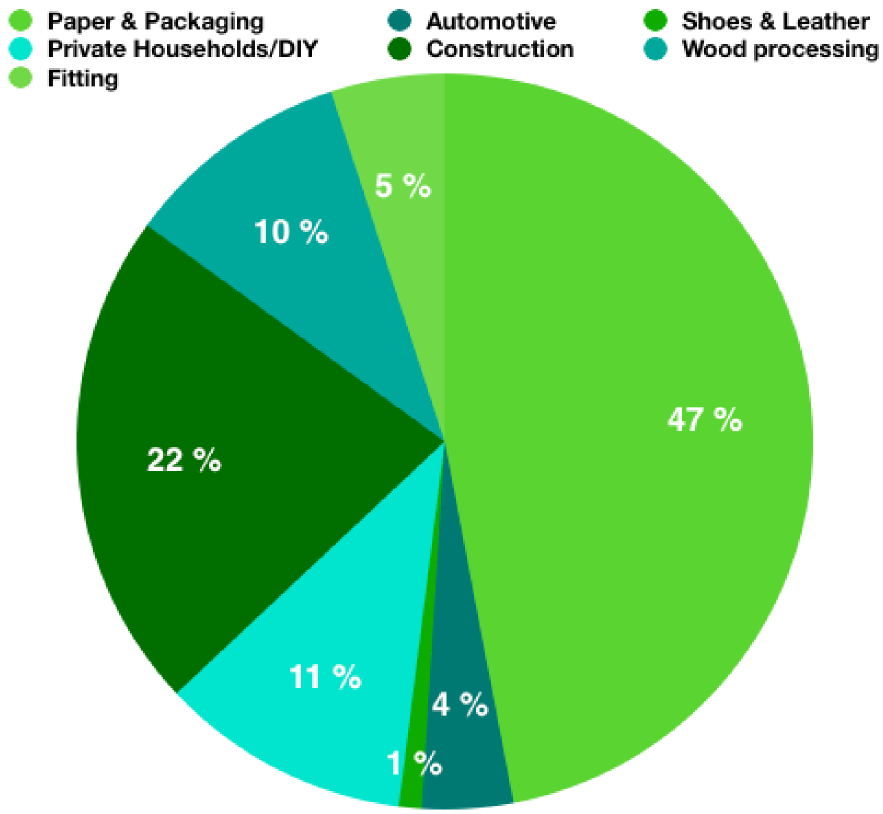

Fig. 3.3 Water-based dispersions by branch (Germany, 2018, source: IVK 2019)

Import has also grown from 431 M€ (2008) to 752 M€ (2018). The same holds for export numbers which are 1,015 M€ (2008) and 1,946 M€ (2018). All numbers have been provided by IVK. Detailed information on the distribution of product types could not be obtained.

Water based adhesives are formulated either as dry powders or as prepared solutions or dispersions. Producers or distributors have to mix these precursors with water (and additives) to produce an adhesive. Adhesive properties result from evaporation or absorption (by the substrate). Therefore at least one substrate has to be permeable. As polymers in water-based adhesives are soluble in water the bonds between surfaces are susceptible to humidity and water, although some adhesives are produced from insoluble base materials like plant or casein glues.

Water based adhesives, which are relevant for this project are mostly polymer dispersions. They are used in multiple areas such as packaging, foil laminating, building, wood bonding, ceramic tiles fixing, bookbinding, cold seal, or automotive assembly (Gillat, 2005). One can distinguish between four major types of water-based adhesives (NPCS 2008):

- vegetable glues
  are based on starch; they are important for applications like bookbinding; they are very durable but sensitive to humidity
- glues from animal protein
  are produced from animal organs or from milk proteins; hot glues are primarily used for quick-fix-applications, water and moisture resistant casein adhesives are mainly used in beer and wine bottling industry
- resin/polymer acetates
  vinyl acetate, ethylene vinyl acetate, acryl resin emulsion polymers are primary components; these adhesives, which have a white colour, produce clear, flexible connections of paper as well as wood or plastic
- latex adhesives
  are produced from emulgated elastomers, or rubbers; they are for bonding stamps, envelopes, fabric, leather, and wood.

According to Ebnesajjad and Landrock (2014) “adhesives resemble paints in formulation in that they may contain a number of components in addition to the adhesive materials, which are also called the *binders*. Every component is not found in every adhesive. For example, not all adhesives contain a solvent or filler.”
Key components that may be found in commercial adhesives are (Ebnesajjad and Landrock, 2014):

- Adhesive base or binder (e.g. the resin)
- Hardener (for thermosetting adhesives)
- Solvents
- Diluents
- Fillers
- Carriers or Reinforcements
- Other additives: plasticisers, accelerators, inhibitors, retarders, tackifiers, thickeners, film formers, antioxidants, antifungal agents, and surfactants.

According to (Gillatt, 2005) the polymer dispersions in general have a pH range between 3.5 and 9.5 with acrylic polymers having a pH > 8. Oftentimes it is the pH range, which determines the susceptibility to the various classes of microorganisms with acidic dispersions favouring growth of yeasts and moulds, while neutral to alkaline conditions tend to support the growth of bacteria.

3.4 Biocidal agents for in-can-preservation of water-based coatings and adhesives

3.4.1 Overview

Microbial activity in water-based coatings and adhesives has to be controlled in order to protect production facilities, product, and users. Under the Biocidal Products Regulation the active substances as listed in Table 3.7 are currently approved (11), not approved (3), or under review (38) for use as in-can preservatives (PT 6). The list and the classification regarding target organisms was supplied in (Interview 1). It was updated in March 2020 by comparing the list with recent data from ECHA.

Table 3.7 Active Substances for Product Type 6

Active Substance(s)	CAS	Status	Class
Chlorocresol (CMK)	59-50-7	Approved	
Glutaral (Glutaraldehyde)	111-30-8	Approved	
N-(trichloromethylthio)phthalimide (Folpet)	133-07-3	Approved	fungicide
Hydrogen peroxide	7722-84-1	Approved	
3-iodo-2-propynylbutylcarbamate (IPBC)	55406-53-6	Approved	fungicide
Peracetic acid	79-21-0	Approved	
CMIT/MIT	55965-84-9	Approved	bactericide and fungicide
Biphenyl-2-ol (OPP)	90-43-7	Approved	
N,N′-methylenebismorpholine (MBM)	5625-90-1	Approved	
2-bromo-2-(bromomethyl) pentanedinitrile (DBDCB)	35691-65-7	Approved	
MBIT	2527-66-4	Approved	bactericide and fungicide
2-octyl-2H-isothiazol-3-one (OIT)	26530-20-1	Under review	fungicide
2-Phenoxyethanol	122-99-6	Under review	
7a-ethyldihydro-1H,3H,5H-oxazolo[3,4-c]oxazole (EDHO)	7747-35-5	Under review	
2-Brom-2-nitropropan-1,3-diol (Bronopol)	52-51-7	Under review	bactericide
cis-1-(3-chloroallyl)-3,5,7-triaza-1-azoniaadamantane chloride (cis CTAC)	51229-78-8	Under review	bactericide
Dodecylguanidine monohydrochloride	13590-97-1	Under review	
Ethanol	64-17-5	Under review	
Monochloramine generated from ammonium carbamate and a chlorine source		Under review	
Hexa-2,4-dienoic acid (Sorbic acid)	110-44-1	Under review	
L-(+)-lactic acid	79-33-4	Under review	

Active Substance(s)	CAS	Status	Class
N-(3-aminopropyl)-N-dodecylpropane-1,3-diamine (Diamine)	2372-82-9	Under review	
3,3′-methylenebis[5-methyloxazolidine] (Oxazolidine/MBO)	66204-44-2	Under review	bactericide
p-[(diiodomethyl)sulphonyl]toluene	20018-09-1	Under review	fungicide
Potassium (E,E)-hexa-2,4-dienoate (Potassium Sorbate)	24634-61-5	Under review	
Pyrithione zinc (Zinc pyrithione)	13463-41-7	Under review	fungicide
Didecyldimethylammonium chloride (DDAC (C8-10))	68424-95-3	Under review	
(ethylenedioxy)dimethanol (Reaction products of ethylene glycol with paraformaldehyde (EGForm))	3586-55-8	Under review	bactericide
Sodium 2-biphenylate	132-27-4	Under review	
Pyridine-2-thiol 1-oxide, sodium salt (Sodium pyrithione)	3811-73-2	Under review	fungicide
Tetrahydro-1,3,4,6-tetrakis(hydroxymethyl)imidazo[4,5-d]imidazole-2,5 (1H,3H)-dione (TMAD)	5395-50-6	Under review	bactericide
Tetrakis(hydroxymethyl)phosphonium sulphate (2:1) (THPS)	55566-30-8	Under review	bactericide
Methenamine 3-chloroallylochloride (CTAC)	4080-31-3	Under review	bactericide
Reaction mass of titanium dioxide and silver chloride		Under review	bactericide
Sodium N-(hydroxymethyl)glycinate	70161-44-3	Under review	bactericide
Peracetic acid generated from tetra-acetylethylenediamine (TAED) and sodium percarbonate		Under review	
PHMB (polyhexamethylene biguanide hydrochloride)	1802181-67-4	Under review	
2-methyl-2H-isothiazol-3-one (MIT)	2682-20-4	Under review	bactericide
2-butyl-benzo[d]isothiazol-3-one (BBIT)	4299-07-4	Under review	fungicide
2,2-dibromo-2-cyanoacetamide (DBNPA)	10222-01-2	Under review	
2,2′-dithiobis[N-methylbenzamide] (DTBMA)	2527-58-4	Under review	bactericide and fungicide
2,2′,2″-(hexahydro-1,3,5-triazine-1,3,5-triyl)triethanol (HHT)	4719-04-4	Under review	bactericide
1,3-bis(hydroxymethyl)-5,5-dimethylimidazolidine-2,4-dione (DMDMH)	6440-58-0	Under review	bactericide
1,2-benzisothiazol-3(2H)-one (BIT)	2634-33-5	Under review	bactericide and fungicide

Active Substance(s)	CAS	Status	Class
.alpha.,.alpha.′,.alpha.″-trimethyl-1,3,5-triazine-1,3,5(2H,4H,6H)-triethanol (HPT)	25254-50-6	Under review	bactericide
(benzyloxy)methanol	14548-60-8	Under review	bactericide
Didecyldimethylammonium chloride (DDAC)	7173-51-5	Under review	
Tetrahydro-3,5-dimethyl-1,3,5-thiadiazine-2-thione (Dazomet)	533-74-4	Under review	
Formic acid	64-18-6	Under review	
2-Butanone, peroxide	1338-23-4	not approved	
4,4-dimethyloxazolidine	51200-87-4	not approved	
polyhexamethylene biguanide hydrochloride with a mean number-average molecular weight (Mn) of 1600 and a mean polydispersity (PDI) of 1.8 (PHMB(1600;1.8))	27083-27-8	not approved	

Today the most important agents are isothiazolinones, but formaldehyde donors also play a role. This holds for production inputs like polymer dispersions as well as for the final products. Based on their minimum inhibition concentrations (MIC in mg/l), Paulus (2005) describes the biocidal properties of these substances as follows (Table 3.8).

Table 3.8 Biocidal properties of common isothiazolinones (Paulus 2005)

Substance	CAS	Target organisms	Minimum Inhibitory Concentration (ppm)	
MIT	2682-20-4	bacteria	Escherichia coli (b) Klebsiella pneumoniae (b) Aspergillus niger (m) Candida valida (y)	17.5 20.0 750.0 75.0
CIT	26172-55-4	bacteria	Pseudomonas aeruginosa (b) Pseudomonas fluorescens (b)	0.6 0.2
CIT/MIT	26172-55, 2682-20-4	bacteria fungi	Escherichia coli (b) Klebsiella pneumoniae (b) Aspergillus niger (m) Candida albicans (y)	9.0 9.0 9.0 9.0
OIT	26530-20-1	fungi	Escherichia coli (b) Klebsiella sp (b) Aspergillus niger (m)	75 125 5-10
BIT	2634-33-5		Escherichia coli (b) Pseudomonas aeruginosa (b) Aspergillus niger (m) Candida albicans (y)	25 150 100 200

b: bacteria, m: moulds, y: yeasts

Gillat (2005) points out that MIT and BIT have similar biocidal properties „with both being effective against the majority of species tested (with the exception of A. niger) at between 10 and 200 ppm“, but that a 1:1 blend shows synergistic biocidal properties and therefore has become a very important choice for the preservation of polymer dispersions and other formulations (see Table 3.9).

Table 3.9 Minimum inhibitory concentrations of pure and mixtures of MIT and BIT (Gillat 2005)

	Minimum Inhibitory Concentration (ppm)		
Organism	MIT	BIT	MIT/BIT (1:1)
Escherichia coli	17.5	25	10
Klebsiella pneumoniae	20	25	15
Proteus vulgaris	25	20	10
Pseudomonas aeruginosa	30	150	20
Pseudomonas putida	12.5	60	10
Pseudomonas stutzeri	12.5	20	10
Aspergillus niger	750	100	50
Paecilomyces variotii	100	40	20
Penicillium funiculosum	200	40	20
Saccharomyces cerevisiae	150	15	10

Jensen (2019) points to the danger of tolerance and resistance to biocides, which typically occurs when microorganisms are exposed to a single active ingredient or to sublethal doses of active ingredients.

3.4.2 Requirements for in-can preservatives

Leroy (2019) states that of the roughly 50 active substances currently approved or under review for PT 6 (of which are three „new“) only a few are technically suitable for use with paints or coatings. CEPE, together with three other European industry associations assembled an evaluation regarding the usability of 47 biocide actives under the current review program (AISE et al. 2014, Annex I). Technical limitations were described as follows (see Table 3.10).

Table 3.10 Technical limitations of biocide actives under the current review program (AISE et al. 2014)

Substance or substance family	**Technical Limitations**
Formaldehyde releasers (13 active substances)	CH_2O has limited activity on yeasts and moulds
BIT	intrinsically ineffective on Pseudomonas, very oxidant unstable
Mixture of CMIT/MIT 3:1	use is limited to 15 ppm to avoid classification, some Pseudomonas tolerances met at this concentration level
MIT	weak against fungi but very good on bacteria including Pseudomonas

Substance or substance family	Technical Limitations
OIT	good fungicide, limited bactericide
BBIT	short shelf life
DTBMA	can in certain matrices degrade to MBIT, which is an isothiazolinone
IPBC	limited antibacterial activity, intrinsically ineffective against Pseudomonas, good fungicide; chemically unstable, risks of discoloration
Bronopol	high concentration needed, chemically very unstable, risks of discoloration
Zinc pyrithione	high concentration needed, limited antibacterial activity, intrinsically ineffective against Pseudomonas, very oxidant unstable, risks of discoloration
Sodium pyrithione	limited performance
2-Phenoxyethanol	overall limited activity, very limited against bacteria, ineffective on Pseudomonas, smells, VOC, very high concentration needed
Formic acid	limited performance, pH and odour issues
Dazomet	short shelf life (hydrolysis in water)
DBDCB	short shelf life in comb. with nucleophiles, alone weak performance, suitable in combinations e.g. BIT for some applications
L-(+)-lactic acid	limited performance, pH issue
Hexa-2,4-dienoic acid / Sorbic acid	limited performance, pH issue
Potassium Sorbate	limited performance, requires high concentration, which loads salt
DBNPA	short shelf life, used for very short-term treatment (such as raw materials) but not for shelf life preservation
Biphenyl-2-ol	phenol, gives smell; high concentration needed, very weak bactericide, intrinsically ineffective against Pseudomonas , limited availability in the water phase, migrates into polymers/plastics
Sodium 2-biphenylate	phenol, gives smell, limited uses
Dodecylguanidine monohydrochloride	incompatible, surface active
Potassium 2-biphenylate	phenol, gives smell, limited uses

Substance or substance family	**Technical Limitations**
Peracetic acid	short shelf life, pH and high reactivity issues
Glutaraldehyde	short shelf life; can cause cross link reactions hence technically incompatible, destroys enzymes
Hydrogen peroxide	short shelf life
Chlorocresol	phenol, gives smell
Sodium p-chloro-m-cresolate (Covered by chlorocresol)	phenol, gives smell
PHMB	incompatible, surface active, low efficacy
DDAC	incompatible, surface active
Quaternary ammonium compounds, di-C8-10-alkyldimethyl, chlorides (see DDAC)	incompatible, surface active
Diamine	incompatible, surface active, low efficacy
Silver chloride adsorbed to titanium dioxide (initially notified under silver chloride)	limited performance; very limited against moulds and yeasts, relative high concentrations needed, expensive, risks of discoloration
Silver chloride	limited performance; very limited against moulds and yeasts, relative high concentrations needed, expensive, risks of discoloration
p-[(diiodomethyl)sulphonyl] toluene	can cause discoloration, limited uses

In the following requirements for in-can preservatives of water-based coatings and adhesives are detailed based on the expert interviews as described in Table 2.3.

Manufacturers of polymer dispersions (Interview 6) stated that chloromethylisothiazolinone (CIT), benzoisothiazolinone (BIT), methylisothiazolinone (MIT) (ordered by importance) as well as 2-bromo-2-nitropropane-1,3-diole (bronopol) are used. CIT and MIT are applied in concentrations below 15 ppm.

Manufacturers of water-based adhesives (Interview 6) or coatings (Interviews 2, 3, 4, 5, 7) are using these isothiazolinones as well. Here, a mixture of CIT/MIT has some importance. For a long time bronopol only played a minor role, but it is increasing, especially for vapour space conservation. Combinations of BIT with CIT/MIT and/or Bronopol are also important.

In polymer dispersions for adhesives, target organisms are bacteria, yeasts and moulds. This was confirmed both by manufacturers of biocidal products as well as by manufacturers of polymer dispersions (Interview 2, 6, 8).

In coatings, bacteria are of exceeding relevance (90%) as compared to fungi (10%). Regarding bacteria mostly gram-negative species are relevant (e.g.: Pseudomonas). But there are also organisms that prefer specific habitats (e.g. acidophiles at pH 3-5, alkaliphiles at pH 9-12). All relevant organisms can be described as ubiquitous (Interview 2).

Key functionalities of biocidal agents were described as follows (Interview 2):
- they have to effective against the target organisms
- they must be bioavailable in the medium (solid or liquid phase)
- they must be stable in the medium for the necessary period (during production, in-can)
- they must be compatible with the environment (no impact on the product or the production process).

These aspects can be further differentiated as follows:
- Regarding raw materials production (polymer dispersions) the objective is a stabilisation for the transport to the customer. A storage stability of 3 to 6 months is guaranteed (Interview 6). The agent has to operate quickly in the given environment, it has to be stable against the ingredients and it should not lead to a classification as a hazardous substance.
- Regarding adhesive production the biocide has to be stable at neutral to acidic pH. A storage stability of 24 months has to be maintained as this is usually warranted. Viscosity of the product as well as stability of the dispersion must not be influenced.

The most important properties of a biocidal agent usable for adhesive production are:
- stable at temperatures up to 60°C
- stable in pH range of 3,5 – 10
- free of hazardous evaporations, e.g., of adhesively joined parts
- no impact on product properties like colour, smell, viscosity
- not reactive with other ingredients (e.g. no impact on cross-linking mechanisms)
- effective at low concentrations (with raw materials as well as products not having to be classified as dangerous substances/mixtures)
- long-time stability and efficacy in the product
- for adhesives used for food packaging the relevant food regulations have to be observed.

Factors for the usability of biocidal agents in coatings (besides efficacy against target organisms) are comparable as described by interview partners from coatings industry. They can be summed up as follows. Active substances must be
- odourless and colourless
- chemically compatible
- safe to use during product application.

Properties of the mostly used biocidal agents have been described as follows by a manufacturer of biocides:
- CIT is highly efficient both with regard to bacteria as well as fungi, but it has low stability in coatings or adhesives (days – weeks), therefore, it is not useful for long time storage conservation.
- MIT is much more stable, but requires much higher concentrations as compared to CIT.

Other in-can preservatives

Other potentially usable agents are problematic due to diverse reasons (according to one manufacturer of biocidal products):

- Iodopropynyl butylcarbamate (IPBC) is rather applicable in other product types (PT 7, PT 8[3]) as it is a good fungicide but not effective against bacteria. Its water solubility is rather low therefore the availability in the aqueous phase is limited. It is used in combination with other agents as a fungicide wet-state-preservative for pigment pastes and tinters.
- Only a few pyrithione salts are usable (Zn and Na), as other cations result in coloured substances.
- 2,2-dibromo-3-nitrilopropionamide (DBNPA) hydrolyses within a few hours at 25°C and pH above 6 (Paulus 2005).
- Some agents are more problematic with regard to VOC regulations, as well as with regard to adverse indoor emissions.
- Some agents require a multiple times higher concentration and therefore cause a higher exposure as well. The use of substances with low efficacy like, e.g., phenoxyethanol would require much higher concentrations (~10.000 ppm) as compared to isothiazolinones. This would have impacts not only on costs but also on product properties.

The above-mentioned biocides are described by Paulus (2005) as follows (Table 3.11).

Table 3.11 Biocidal properties and BPR status of some discussed potential alternatives to isothiazolinones

Substance	Properties (Paulus 2005)	Status (BPR) Classification
IPBC (CAS No. 55406-53-6)	IPBC is highly effective against a wide variety of fungal species (…) IPBC's spectrum of effectiveness comprises also yeasts, e.g. Candida albicans, Saccharomyces cerevisiae, and in considerably higher concentrations bacteria, too.	Approved, H*: Aq. Acute 1 (H400), Eye Dam. 1 (H318), Acute Tox. 4 (H302), Skin Sens. 1 (H317), Aq. Chron. 1 (H410), Acute Tox. 3 (H331), STOT RE 1 (H372)

[3] Product Type 7: Film preservatives, Product Type 8: Wood preservatives

Substance	Properties (Paulus 2005)	Status (BPR) Classification
Sodium Pyrithione (CAS No. 3811-73-2)	Sodium Pyrithione is a widely used preservative for water based functional fluids. In consequence of its activity spectrum it is preferably applied when problems due to the growth of fungi have to be overcome, e.g. in metal working fluids. Sodium Pyrithione is a highly effective microbicide; the addition rates therefore are relatively low: 0.02–0.06%. However, users of Sodium Pyrithione have to pay attention to the fact that it is a chelating agent which in the presence of, for example, Fe^{2+} ions or Cu^{+} ions is converted to the corresponding chelates. These are sparingly soluble and highly coloured compounds. That means that they can cause colorations and precipitation, thus withdrawing active ingredients from the functional fluid to be protected. The ferric complex is blue, for example, and only a few ppm in a formulation can cause a noticeable discoloration.	Under review, S**: Eye Irrit. 2 (H319), Skin Irrit. 2 (H315), Aq. Acute 1 (H400), Acute Tox. 4 (H302, H332, H312)
Zinc Pyrithione (CAS No. 13463-41-7)	Zinc Pyrithione's spectrum of efficacy covers moulds, yeasts, bacteria and algae. It may be used as an in-can preservative for a great variety of aqueous formulations, including cosmetics.	Under review S**: Aq. Acute 1 (H400), Eye Dam. 1 (H318), Acute Tox. 3 (H301)
DBNPA (CAS No. 10222-01-2)	DBNPA's spectrum of efficacy is broad and equalized. It covers Gram-positive and Gram-negative bacteria, yeast, fungi and algae. In particular remarkable is its effectiveness against slime forming micro-organisms, (…) which are inhibited by 0.5–1 mg/l. Due to its very distinct electrophilic character DBNPA exhibits fast antimicrobial action by reactions with nucleophilic cell compounds such as the protein fractions of the cell membrane and enzyme systems. The rapidity of DBNPA's action requires that one adds the active component to systems „already containing micro-organisms. (…) One can characterize DBNPA as a potent but not persistent microbicide the application of which does not cause waste water problems. Formulations containing 40%, 20% or 5% a.i.[4], are available. (…) As a preservative DBNPA is efficient only for short-term protection of aqueous products.	Under review S**: Acute Tox. 3 (H301), Acute Tox. 2 (H330), Skin Irrit. 2 (H315), Eye Dam. 1 (H318), STOT RE 2 (H373), Aq. Acute 1 (H400), Aq. Chron. 1 (H410)

[4] **a**ctive **i**ngredient

Substance	Properties (Paulus 2005)	Status (BPR) Classification
Potassium Sorbate (CAS No. 24634-61-5)	It is justified to characterise sorbic acid as one of the least toxic of all the preservative agents known. In its undissociated form it is a membrane active agent which due to its unsaturated character additionally may exhibit electrophilic activity. Therefore, sorbic acid is able to penetrate the microbial cell membrane and to inhibit nutrient transport and enzymes. In accordance with its pK_a value of 4.76 sorbic acid is most effective at pH 4 or below in its undissociated form; however, there is considerable antimicrobial activity of sorbic acid observed also at pH values up to 6.0–6.5. This may be attributed to the ability of sorbic acid to partial intramolecular cyclisation to the delta lactone of 5-hydroxy-2-hexene acid, an electrophilic, neutral substance the activity of which is not that much dependent on pH as is the acid. Hence the breadth of application is for sorbic acid larger than for other lipophilic acid preservatives. Sorbic acid inhibits especially the growth of moulds and yeasts; its efficacy against bacteria is not that equalised and consequently not reliable. At addition rates between 0.05 and 0.3 % sorbic acid is used as a preservative for foodstuffs (especially beverages, including wine), pharmaceuticals and cosmetics. The sodium, potassium and calcium salts are also available; the most frequently used salt form is, however, potassium sorbate (CAS-no. 24634-61-5; EC-no. 246-376-1; E 202), because of its high solubility in water (1390 g/l).	Under review H*: Eye Irrit. 2 (H319)

H*: Harmonised classification
S**: Self-Classification of at least 70% of CLP notifications

The aspect that some biocidal products require concentrations that are a multiple times higher than, e.g., MIT, and therefore cause a higher exposure as well has been addressed by some paint and adhesive manufacturers. Lower effective concentrations of biocides in general reduce the impact of the additive on the product conditions, e.g., pH, dispersion stability etc. Moreover, it was stated that biocides are relatively expensive in comparison with other ingredients, which is in itself an incentive to use as little of them as technically possible.

CEPE (2019) supplied some results of an internal survey on uses and volumes of in-can preservative active substances for water-based paints. The following data were extrapolated by CEPE based on the feedback received and an estimate of the total water-based paints placed on the EU market.

Table 3.12 Uses and volumes of in-can preservative active substances for water-based paints (CEPE 2019)

Active Substance	Volume [t]	Remark
MIT	179	due to the classification of MIT with the labelling deadline of 1 May 2020, it is expected that BIT will take up some share
BIT	456	expected to get a 15 ppm threshold for skin sensitization as well, at which level it is not effective and it is not as strong against Pseudomonas sp. as MIT
CMIT/MIT 3:1	38	approved but with a limitation of 15 ppm (for consumer products)
OIT	7	mainly PT 7
Bronopol	427	under revision by Spain and hasn't yet gone through RAC for a classification. Not in use in France due to the release of formaldehyde as by-product (not as active substance)
EGForm	32	formaldehyde releaser, will be classified as Carc Cat 1B.
TMAD	412	formaldehyde releaser, will be classified as Carc Cat 1B.
DTBMA	98	precursor of BIT
DMDMH	1	formaldehyde releaser, will be classified as Carc Cat 1B.
Benzyloxymethanol	0	not in use
IPBC	20	mainly PT 7 substance
Zinc pyrithione	21	mainly PT 7 substance but has PT 6 activities (in combination with others), classification as Repro 1B is proposed
Diamine	7	anecdotal, limited performance
DBNPA	220	mainly a disinfectant of raw materials as it has no shelf life, proposed to be classified as repro 1B

There are no comparable numbers available regarding adhesives. As production volumes of coatings are higher than those of adhesives, it can be assumed that in absolute numbers larger amounts of in-can preservatives are used for coatings than for adhesives.

3.4.3 Occupational safety and health issues

3.4.3.1 Occupational diseases in relevant industries

Since the aim of this study was to give an overview on alternatives for the use of isothiazolinones as in-can preservatives no detailed analysis of occupational health risks during production and during final use of paints and adhesives was done. In the following only some impressions regarding development of occupational diseases raised in the interviews are provided starting with possible risks during production of paints and adhesives.

The production of polymer dispersions is mostly carried out in closed systems. The same holds for adhesive production. In larger companies the manufacture of coatings is also done mostly in closed systems, while in smaller companies biocides are dosed manually by drum pumps. In the cases where closed systems are utilised the highest risk exists in the coupling of delivered product (from IBC or tank waggons) to the internal storage system. Here, respiratory protection and adequate protective clothings are the normal case. In factories, where open system production prevails, PPE is worn while biocides are dosed, and there are also technical exhaust systems.
In general, all respondents from the companies estimated the risks adherent to the biocidal products as comparatively low with regard to health or physico-chemical risks resulting from other chemicals in use. For example, in open systems paint production risks resulting from particulate matter are estimated to be more serious.

OSH experts from the workers' compensation boards of relevant branches were contacted with the following results:

- The workers' compensation board of raw materials and chemical industry reported that in from January 2009 to December 2018 there were 15 cases of occupational disease with regard to isothiazolinones confirmed. One case concerns an obstructive respiratory disease while the other 14 cases were skin allergies. The general estimate was that there are no relevant precarious findings regarding sensibilisation by isothiazolinones.
- The workers' compensation board of wood and metal industry reported to have no information or findings on the subject.
- The workers' compensation board of energy utilities, textile and electrical industry and media product industry reported that in the last 20 years there were three confirmed cases of skin allergies caused by CIT/MIT while annually there are between 150 to 200 suspected cases notified for this branch. It must be noted that the respondents also mentioned that protection from a respiratory exposure to microorganisms is much more difficult than protection from dermal exposure to biocidal products.
- No need for specific action to address risks due to the use of CIT/MIT as in-can preservatives in the printing and paper processing industry was raised.
- The risks for workers using the end products (adhesives or coatings) were discussed with the workers' compensation board of construction industry (BG BAU). Risks of skin sensitisation from biocides in paints or adhesives were seen by the BG BAU expert as relevant but relatively low as compared to those posed for example by epoxy resins.

3.4.3.2 Incidence of skin sensitisation in Painters and Lacquerers

Allergic contact dermatitis is the clinical manifestation of a sensitisation to a specific substance, which is usually acquired by direct skin contact. Mostly, allergic contact dermatitis is elicited by direct skin contact to the allergen. However, several allergens are volatile and may cause airborne contact dermatitis in sensitised individuals (Swinnen and Goossens 2013, Veien 2011).

In a study funded by the Federal Institute for Occupational Safety and Health (BAuA) the Information Network of Departments of Dermatology (IVDK) provided frequencies of sensitisation to specific substances and to specific occupation groups. In the field of contact allergy, the IVDK holds the world largest database with patch test results and clinical data of more than 250.00 patients from 56 departments of dermatology. Based on IVDK data of the years 2007 to 2016 (120,977 patients) an overview of tested allergens which elicited positive reactions and with reaction frequencies was provided covering also the occupational group of Painters, Varnishers and related workers. 405 Painters, Varnishers and related workers are diagnosed to have a occupational dermatitis (OD) (2.1% of 18,877 all patients with diagnosed OD).
As contact allergens from the chemical group of preservatives patients were tested for the sensitiser Methylisothiazolinone (MIT), Methylchloroisothiazolinone / Methylisothiazolinone (MCIT/MIT), Benzisothiazolinone (BIT), Octylisothiazolinone (OIT), Propolis, Formaldehyde and quaternium 15 (formaldehyde releaser). For comparison also the reaction frequencies to sensitising allergens of epoxy resin systems which are used as resins, reactive diluents and harderners are shown.
Table 3.13 gives an overview on the frequency of positive tested patients with a diagnosed allergic contact dermatitis from the occupational group of painters, varnishers and related workers (2007 to 2016).

Table 3.13 Frequency of positive tested OD patients, 2007-2016 (own table, based on IVDK 2020)

Contact allergen	Percentage of OD patients from the occupational group of Painters, Varnishers and related workers with positive reaction to the allergen	Percentage of OD patients from all occupational groups with positive reaction to the allergen
Epoxy resins	10.2%	3.7%
Methylisothiazolinone (MIT)	7.0%	6.9%
Methylchloroisothiazolinone / Methylisothiazolinone (MCIT/MIT)	5.2%	5.8%
Benzisothiazolinone (BIT)	-	-
Octyl isothiazolione	-	1.3%
Propolis	1.2%	2.5%
Formaldehyde	0.9%	1.9%
Quaternium 15	-	1.0%

For comparison with DGUV data on confirmed occupational diseases a separate evaluation of the IVDK database for the shorter time period 2013 to 2015 was done (patients with OD in total: 6,019; painters, varnishers and related workers with occupational dermatitis: 137) (Table 3.14). Frequencies are quite similar to OD incidence rates calculated from DGUV data.

Table 3.14 Frequency of positive tested OD patients, 2013-2015 (own table, based on IVDK 2020)

Contact allergen	**Percentage of OD patients from the occupational group of Painters, Varnishers and related workers with positive reaction to the allergen (sensitised patients)**
Methylisothiazolinone (MIT)	21.10%
Methylchloroisothiazolinone / Methylisothiazolinone (MCIT/MIT)	14.8%
Epoxy resins	12.2%
Propolis	2.3%
Formaldehyde	1.6%

A relevant share of OD patients from the group of painters and varnishers show a positive test result to MIT and MCIT/MIT which are used as active substances for in-can preservatives. But, MIT was also used to large amounts in cosmetics and now has been either banned (in leave-on products like skin cream) or limited (in soaps etc.). Therefore, a conclusion on whether these sensitisations are caused by occupational exposures or by cosmetics like skin creams is difficult to draw.

4 Potential alternative products and concepts

4.1 Overview

To date only very few potential alternatives to isothiazolinones or formaldehyde donors have been named.
The European coatings industry together with the International Association for Soaps, Detergents and Maintenance Products (CEPE and AISE, 2018) have produced an extensive overview on the usability of all active agents that are listed as in-can preservatives. They conclude that of this list only 15 substances are usable for coatings, with isothiazolinones forming the largest substance family:

- 3-iodo-2-propynylbutylcarbamate (IPBC)
- Mixture of 5-chloro-2-methyl-4-isothiazolin-3-one and 2-methyl-4-isothiazolin-3-one (CMIT/MIT)
- 2-bromo-2-(bromomethyl)pentanedinitrile (DBDCB)
- octyl-2H-isothiazol-3-one (OIT)
- 2-Brom-2-nitropropan-1,3-diol (bronopol)
- Zinc pyrithione
- (ethylenedioxy)dimethanol (Reaction products of ethylene glycol with paraformaldehyde (EGForm))
- Pyridine-2-thiol 1-oxide, sodium salt (Sodium pyrithione)
- 2-Methyl-1,2-benzisothiazol-3(2H)-one (MBIT)
- 2-methyl-2H-isothiazol-3-one (MIT)
- 2-butyl-benzo[d]isothiazol-3-one (BBIT)
- 2,2′-dithiobis[N-methylbenzamide] (DTBMA)
- 1,2-benzisothiazol-3(2H)-one (BIT)
- (benzyloxy)methanol

Other substances are not seen as usable due to reasons already described in Table 3.10. The major drawbacks, which vary from substance to substance can be summed up as follows:

- limited activity on certain target organisms
- limited chemical stability (therefore short shelf life)
- risks of discoloration
- limited performance
- pH and/or odour issues
- substance classified as VOC
- very high concentration needed
- limited availability in the water phase, migrates into polymers/plastics
- incompatible due to surface active behaviour or reactivity with base materials.

Most manufacturers in cooperation with their suppliers are thinking about combinations of these already listed substances. One manufacturer of "natural" coatings uses MIT/BIT and is preparing to use a mixture of BIT and sodium pyrithione.

In the case of mineral paints, the option of higher alkalinity (~pH 11, just below the classification level) is realised by several paint producers. But today this is valid only for white paints. For polymer dispersions higher pH is no option as alkaline hydrolysis

would set in. The same holds true for adhesives on paper or wood where the high pH would affect the base materials according to some adhesives manufacturers. One manufacturer of biocides pointed out that even under alkaline conditions bacterial growth is not completely prevented. Any species adapted to those conditions would be virtually without competition and therefore could be growing totally unregulated.
One adhesive manufacturer named sorbates as possible alternative but pointed out that these substances are active at concentrations of about 5,000 ppm. At these comparably large quantities it cannot be ruled out that the additive has negative repercussions on product properties.

4.2 Alternative products

Rees (2016) described the situation in a technical paper for The Pressure Sensitive Tape Council (PSTC): „*Despite regulatory pressures reducing the number of biocide molecules from which to choose (or their concentrations in end-products), blends of carefully selected actives in optimal ratios, coupled with new technical advancements are able to provide improved preservation solutions without the need for cautionary labelling.* (…) *Choosing the correct biocide for any particular application requires consideration of multiple variables, and is best done with specialist assistance from a reputable biocide manufacturer.*“

This approach can be described by an example of German manufacturer Schülke (2017) who presented two MIT free alternatives (Table 4.1).

Table 4.1 Examples of two MIT free biocidal products for coatings

Product 1	**Product 2**
Active substances: phenoxyethanol, butylbenzisothiazolinone (BBIT) and laurylamine dipropylenediamine (BDA)	Active substances: benzisothiazolinone (BIT), sodium pyrithione (NaPT) and BDA
Fast and effective preservative with broad application spectrum	
Long-time protection in final product	
Synergistic active substance combination with additional fungicide effect	Optimised active substance combination with additional fungicide effect
Application concentration: 0.5 – 1 %	Application concentration: 0.05 – 0.20 %
Vapour phase efficacy	
Excellent pH and temperature stability (max. pH 11)	
Free of formaldehyde, AOX, VOC and Alkylphenolethoxylate (APEO)	
PT 6 + PT 13	PT 6

This example shows that producers are trying to move away from MIT, but as Jensen (2019) points out, some of the alternative active substances (BIT and sodium pyrithione) used in the products described above might not be usable in the future as the expected SCL for BIT is 15 ppm and as pyrithione sodium might be classified like pyrithione zinc as Repr. 2 and therefore be excluded from future uses.

As MIT has been used extensively in cosmetics and now has been either banned (in leave-on products like skin cream) or limited (in soaps etc.) it was analysed, which

alternatives were employed in this sector. Contacts from interviews (Interview 1, Interview 2) gave the following information: MIT is substituted in cosmetics by very mild preservatives, especially organic acids and alcohols. Substitutes for isothiazolinones in the cosmetic sector are phenoxyethanol, benzoic acid, sorbic acid und methylparaben (Interview 1).
In general, this leads to a significant increase of substance concentration in order to be effective. The use of organic acids requires a pH below 7 while alcohols are relevant with regard to VOC reduction. This situation does not translate to the coatings sector, because of the following reasons (Interview 2):

- Effective concentrations are too high
- Benzoates or sorbates hydrolyse under alkaline conditions
- Alcohols are relevant with regard to regulated VOC emissions.

With regard to adhesives there are some products with rather low pH where benzoates or sorbates could be used as in-can preservative (Interview 6).

4.3 Dry paint base materials

One manufacturer (Interview 7) stated that about 20 years ago the company had tried to market “dry wall paints”. These were to be prepared like mineral plastering: add water, add powder and then stir again after the swelling time. The resulting mixture could be applied like a “normal” paint. The product was offered in white and light pastel colours, which were manufactured in the factory. Intensive colouring was not possible at least at the time. Preparation of colouring at the "point of sale", which is an essential requirement nowadays, e.g. in hardware stores, was and still is not possible. The technical systems for such decentralised tinting systems do not exist. Adjustment of individually requested special colours is hardly possible. Not all shades and colour intensities can be produced by “dryable” pigments.

Obvious advantages of this concept are seen as:

- abdication of preservatives
- packaging waste reduction
- lower energy consumption during transport
- practically unlimited shelf time as well as storage time at the customer’s; therefore, feasibility of use even years later and thus possibly less waste of “old colours”.

Relevant drawbacks for users are:

- “mixing errors” like adding too much water or inadequate stirring can lead to complaints quickly
- availability of adequate tools (mixing container, whisk etc.) to ensure sufficient dispersal of the powder cannot be taken for granted, especially in case of DIY users.

Therefore, it is still seen as questionable whether these products would have the necessary acceptance both with commercial as well as with DIY customers.
The recent classification of titan dioxide[5] was seen as an important obstacle for dry paints being an alternative for the general public as long as there is no viable alternative to titan dioxide as a white pigment.

[5] The 14th Adaptation to Technical Progress to the CLP regulation (C(2019) 7227 final) was adopted by the European Commission in October 2019. It amends Annex VI of the CLP regulation by classifying titan dioxide as a carcinogen by inhalation with regard to mixtures in powder form containing 1% or

At the 2019 European Coatings Show Wacker Chemie AG presented a product line based on spray-dried polymeric binders suitable for producing interior wall paints in either liquid or powder form (Wacker 2019). The company states "*Paint manufacturers can use Nexiva to create individual paint formulations, just as they can with traditional binders in dispersion form. Powder paints remain stable, even without the addition of preservatives. Water for redispersing the paints is not added until just prior to application, thus eliminating the need for adding biocides during production. As the paint dries, all that evaporates is water. Thanks to the polymers, the paint adheres well and has good spreading properties. In addition, paints are easier to transport and store when they are in powder form, as they weigh less, for instance, and can be packaged differently from liquid paints.*" (Wacker 2019).
The concept is depicted in Fig. 4.1.

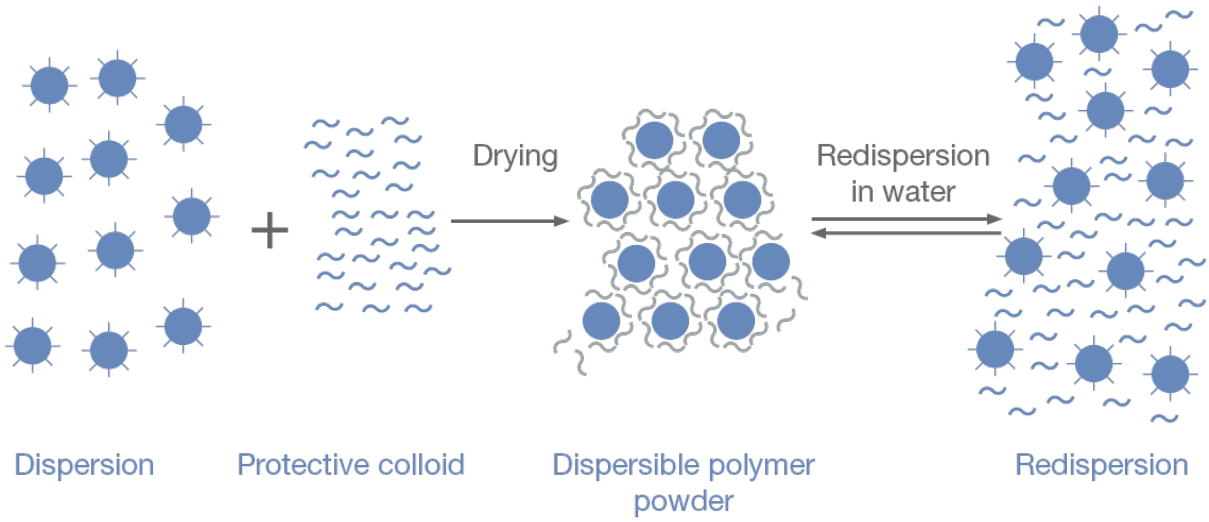

Fig. 4.1 Principle of dry dispersible polymer powder (Illustration: Wacker Chemie AG 2019a)

The product series NEXIVA is a dispersible polymer powder binder and is produced in an integrated production process: First, the liquid polymer dispersion based on vinyl acetate-ethylene and a protective colloid run through a spray dryer. The protective colloid matrix then separates the polymer particles in the powder agglomerates from one another and prevents the polymer particles from irreversibly forming a film during drying and storage. Finally, upon addition of water, the dispersible polymer powder is readily redispersed into individual polymer particles.

The products are presented on the company's website (Wacker 2019a). On enquiry it was confirmed that positive tests of adhesive applications have been made and that in Europe as well as in China products for adhesives are available. There was no mentioning of any paint products, but there is a video presentation available on the internet[6]. In this the following advantages are named, which are comparable to those reported by (Interview 1):

- no need for biocide preservation

more of titanium dioxide which is in the form of or incorporated in particles with aerodynamic diameter ≤ 10 μm.

[6] https://www.youtube.com/watch?v=JvQgob7PvN0

- very low VOC concentrations
- light weight for easy transport
- preparation on demand
- reduction of plastic waste
- colouration possible
- storage at challenging conditions (heat, cold).

4.4 Research on new active agents and biocidal products for in-can preservation

In the course of this project no relevant research activities targetting the development of new active substances for in-can preservatives could be identified. According to the interview partners this is mainly due to economic reasons, which will be further elaborated in this section.

Bruns et al. (2005) state:
„*Active ingredients are without any doubt the most important factor of success in the material protection business. Basically, the whole business relies on the availability of biocides which combine high efficacy and good application properties on the one hand with low cost and promising ecotoxicological properties on the other hand.*“

After pointing to the fact that „*a lot of the important market products of today are based on relatively “old” biocides which have been introduced into the market many years ago*“ (ibid.) they not only name the reasons for this situation (much longer lifecycle of active ingredients in material protection as compared to agrochemical or pharmaceutical applications, increasing costs for R&D and registration), but they also predict that this situation will become more critical as under the European Biocidal Directive (note: at that time the BPR was not in force). Approval costs will reach 4 – 5 million € for each active ingredient, which will lead to a decrease in the number of available biocidal substances (they even give numbers: from 1,500–2,000 in 2005 to less than 300–500 in the future) as well as a decline in product introductions (Bruns et al., 2005).

Quérou (2019) basically confirms these statements. He describes the following essential steps for bringing a new active substance and subsequently a new biocidal product to the market (Table 4.2).

Table 4.2 From invention to innovation (Quérou, 2019)

Activity	**Time frame (years)**	**Costs (M€)**
Identification of candidate new active	3 – 5	5 – 100
Scaling up and preparation of application for approval	3 – 5	5 – 10
Approval, product authorisation and launch	4 – 7	1 – 2

He then names relevant market challenges regarding biocides (Quérou, 2019):

- The market for biocides is small: global sales are about 6.5 bn $ as compared to 950 bn $ for pharmaceuticals or 60 bn $ in the case of pesticides.

- R&D investments in biocides cannot be compared with other life science industries (pharmaceuticals in EU: € 50 Bn/year), but similar diligence is requested in identifying compounds.
- The market is diverse and fragmented with targeted markets often smaller than 50 M€.
- Not all downstream users' sectors are ready or able to pay for innovation.

These statements in their core have been confirmed to date by all interview partners:
- Manufacturers of biocidal products are not doing systematic research for new active agents for in-can preservatives.
- They are also not aware of such activities in the public sector.
- None of the interview partners could name a research institute (public or private), which is active in this field.

The stated reasons for this situation reflect in general the description of Bruns et al. or Quérou. Some interview partners concretised these general statements as follows:
- Due to the existing restrictions with regard to human health, environmental protection combined with the complex requirements of the diverse products to be preserved no interview partner could name potential new candidates for future active agents.
- The necessary time for R&D for a new agent from research to approval is estimated to be 7 to 10 years. Within this time frame further legal restrictions or other changes within the legislative framework cannot be excluded.
- Approval costs (with insecure outcome) for a new agent are concerned high and are estimated to be about 5 million €.
- The market volume (tonnage, sales) for biocidal products is low as compared to agricultural or pharmaceutical applications with PT 6 itself forming only a small segment of this market.

One manufacturer of biocidal products described their position as follows:
- Research institutes who are focussed on new biocides for product type 6 are unheard-of. Some institutes are working on biocidal active substances but without a specific focus on in-can preservatives.
- R&D with regard to new biocidal products is done within the companies, but foremost as combinations of well-known agents.
- In general, specific research on active agents is hard, because it is costly, tedious, uncertain and the chances of future earnings are small as the biocides market is much smaller than, e.g. for pharmaceuticals or pesticides (with PT 6 being only a segment of all biocides).
- In contrast to antibiotics or pesticides for biocidal products an unspecific effect is intended. The former target on pathogens, specific host-target-interactions and specific modes of action while the latter targets all microorganisms, with non-specific host-target-interactions and non-specific modes of action.
- In contrast to research for pesticides or antibiotics there are no specific mechanisms or end points to be addressed in the research for biocidal active agents. This means that options like *in silico* modelling are more or less unavailable.
- Biocidal agents per se have to have some toxicological properties. Therefore, the registration process sets a high bar. It can be passed only after successful research and availability of the complete dataset as required by BPR (incl. applications research, human and ecotoxicology).

- Transfer from other product types does not seem reasonable. Only agents in product types regarding aqueous systems could be relevant (e.g., PT 11,12, 13). But there are already many overlaps (e.g. MIT in cooling lubricants, CIT/MIT in process waters).
- Pesticides are not relevant for PT 6, but could be for, e.g., PT 7 to 10.
- A transfer from antibiotics bears the danger to foster resistances.

In sum, this company does not see research on new agents as a reasonable approach, because there is a good knowledge base on the existing agents and long and proven experience in their safe handling. In contrast, totally new agents (after approval) would be placed on the market with only a comparably small database and without any practical experience both with regard to potential applications as well as regarding potential risks.

In one brief phone interview with a public research institution focussing on adhesive technologies (Interview 14), it was pointed out that also this institution would like to do research on certain plant-based preservatives (for adhesives) but due to the reasons described above there is no funding available.

5 Measures to reduce biocide use

5.1 Process and plant hygiene

There are multiple sources of microbial contamination in a process plant.
It starts with airborne contamination. For example, one interviewee (Interview 6) reported on the impacts of a nearby recycling plant, which had to be dealt with by installing additional filters on some storage tanks.
The next important aspect is water quality, which is monitored in the adhesive industry (Interview 6). While during polymer production any microorganisms tend to be destroyed, some spore-forming organisms and yeasts can survive the process. In storage tanks between water supply and the production plant biofilms can forms as well as in adjacent pipes (Gillatt, 2005). Furthermore, for some twenty years there have been increasing activities to save and to recycle process water. The concept of cleaner production (in German: „Produktionsintegrierter Umweltschutz" or PIUS, see, e.g. VDI 2012), which focuses on closing water circulation, reuse of washing waters etc. has become state of the art in many industries, in some branches creating an important microbiological issue.

In paint production many raw materials are mined goods (e.g., pigments, mineral fillers etc.) and therefore microbially contaminated. According to the interviews (Interview 2, 6, 13) it is not feasible to kill all germs in the raw materials, although most companies request a low level of bacterial activity from their suppliers.

All interview partners stressed the high importance of plant and process hygiene. The same holds for the biocide manufacturer. In fact, the latter are in close communications with their customers on this issue and support them, e.g., by doing microbiological analytics. As was described by some interview partners (Interviews 2, 6, 8, 11, 13) the standard operating procedures include the use of biocides in process waters and in equipment cleaning. Relevant active substances are e.g., DBNPA, bronopol or CIT which are highly effective for short-term preservation of raw materials, process waters, precursors and products in tanks, pipes and operating equipment.

All interviewees claim that hygiene standards as in food production are not feasible. It would require large investments with high operational cost (e.g. for treatment/disinfection of all raw materials). But there are also some specific technical issues that are hard to control.

Coatings and adhesives are built for purpose to cling to surfaces which makes cleaning processes much harder than for many products of food industry. While for the latter it is often sufficient to flush pipe works with hot water, to remove remainders in the pipe systems of paint production may require higher pressure or even mechanical efforts.

One manufacturer of biocides describes its view as follows.

- Even if some basic principles hold in general, it is not possible to find cross-the-board solutions, because the plants, processes, raw materials, customer expectations or label requirements (e.g., is there interest in using the "blue angel" label or not) etc. are too diverse. Plant hygiene is no novel concept. But the awareness within the companies and the willingness to take action are "statistically distributed".

In theory, there should be a high self-interest of the companies as returns of spoiled products in a larger scale would cause serious damage to business.

- In practice this would mean to optimise use of biocides according to plant and product specific requirements, because a well-functioning preservation of the plants (and the bulk products therein) is more important than the preservation of the packaged product. The latter as a rule does not require a fast and strong agent but rather a durable product that is effective for a longer period. Within the factory fast and strong working agents could be used to protect the bulk product, raw materials, pipe systems and tanks. One option would be to manage processes and biocide application under the given, complex constraints in a way that the strong and fast working agents are not contained in the end product. This requires that the available pool of applicable active agents is not reduced further.

One discrepancy was noted between the statement above and some remarks by adhesive manufacturers. The latter claim that even if a food-production-like grade of sanitation could be achieved in production this would not significantly reduce the need for in-can-preservation, because of the long-warranted storage periods of up to 24 months.
Most interview partners knew of the study by Danish EPA (2018) on options to reduce biocide concentrations for preservation of water-based paints. They claimed that the aspects as described therein (combination of agents, booster additives, plant hygiene, impact of raw materials on biocidal efficacy) are all well-known considered. But none of the aspects in itself pose a universal solution, because of the multitude and complexity of products and production conditions.

5.2 Application hygiene

In order to be able to optimise preservative use, interview partners from the adhesive industry stressed that process hygiene at the client side in general poses a greater problem than process hygiene during production (Interview 6). Therefore, it is consistent that adhesive manufacturers provide their clients with hygiene guidelines.

This is illustrated by excerpts of the respective guidelines of one company (Jowat 2019):
„Modern formulations (…) have a better environmental compatibility than in the past. But this also means they provide an ideal breeding ground for the growth of microorganisms like bacteria, mould and yeast fungi. Contaminations can lead to a change in viscosity, the formation of odours and gases, discolouration, a shift in pH value, or even to the growth of a visible mould layer (biofilm) on the surface of the adhesive. In short, contaminations have a detrimental effect on the quality of the adhesive, and can make it unusable in the worst case. (…) The already limited amount of preservatives added to dispersion is further restricted by new legal requirements. (…) As a consequence, the contamination risk of dispersion adhesives with microorganisms will increase in future, making it more important than ever that a minimum level of hygiene be maintained.“
Especially the following aspects are covered in greater details:

- Cleaning, disinfecting and optimal planning of operating equipment
- Personal hygiene of employees and work place
- Protection from airborne contamination
- General hygiene and maintenance.

6 Summary

Water-based varnishes, paints and adhesives require conservation with in-can preservatives. This applies to their raw materials as well as for the end products in order to warrant the necessary shelf life. Currently especially formaldehyde donors and isothiazolinones are relevant in-can preservatives for coatings and adhesives.
But there are also undesirable effects as the former can induce allergical skin reactions and the latter being classified as carcinogen of category 1B and therefore under obligation to be phased out in the future. The whitelist of in-can preservatives (Project type 6 under the Biocidal Products Regulation) names 52 active substances, eleven of which are approved, three are no longer approved.

The survey focussed on several aspects:

- a comprehensive description of the current situation with regard to currently used biocidal products, their application fields, technical requirements as well as hazards in the workplace
- information on research on new active substances and their advantages and/or drawbacks and
- a compilation of information on techniques to reduce bacterial loads in the production process.

Expert interviews formed the basis of the project. Interview partners were acquired from the concerned industry branches and from workers' compensation boards. Additionally, literature of the last ten years was investigated in order to get a diverse overview on the situation.

Comprehensive descriptions of the current situation were given by the interview partners regarding market shares, production volumes as well as, e.g., occupational safety and exposure. Production facilities range from small or medium scale manufactures to large scale industrial production with the former having higher potential workplace exposure and the latter mainly utilizing closed systems. Neither discussions with industry representatives nor information obtained by workers' compensation boards revealed substantial concerns for a high occupational risk resulting from any step of in-can preservatives production or their final use in water based paints, varnishes or adhesives. In some cases the basis for previous and ongoing regulations is not grounded on the evaluation of substances as in-can preservatives but on their application in cosmetics. As a consequence, pointed out by all interviewed industry experts, potential options for active substances for in-can preservation of water-based coatings and adhesives are drastically narrowed.

Literature search on the subject of alternative biocidal agents did not deliver promising findings, which was in line with interview results. According to all interview partners as well as some literature sources there is basically no active research on “new” active substances for in-can preservatives. The following reasons were named likewise in basic literature (Paulus 2005) as well as in more or less all interviews with industry representatives:

- The market is diverse and fragemented leading to a low market value. Low market value means also low interest in R&D investments.
- Biocide users are either unwilling or unable to pay for the necessary innovation processes.

- There is a long time span (seven to ten years) from research to approval, which leads to the risk that a so-far available alternative substance is later identified as an “regrettable substitute”.

As major consequences
- no private research is done regarding “new” biocidal agents, because it is costly, tedious, uncertain and chances of future earnings are small and
- R&D with regard to new biocidal products is done within the companies, but foremost as combinations of existing well-known agents.

The question of agent transfer from other fields of application was discussed with experts but delivered no results, because agent transfer from pesticides is not relevant for PT 6, but could be for e.g., PT 7 to 10, while a transfer from antibiotics bears the danger to foster resistances. Transfer from other biocides of other product types also does not seem reasonable. Only agents in product types regarding aqueous systems could be relevant (e.g., PT 11, 12, 13). But there are already many overlaps (e.g. MIT in cooling lubricants, CIT/MIT in process waters).

Regarding research for new active substances major differences between biocidal agents and antibiotics or pesticides could be identified. Antibiotics or pesticides target on pathogens, specific host-target-interactions and specific modes of action, while biocides target all microorganisms, with non-specific host-target-interactions and non-specific modes of action. Therefore, there are no specific mechanisms or end points to be addressed in the research for biocidal active agents. Thus, options like *in silico* modelling are more or less unavailable.

Part of the approval process is the compilation of information about toxicological properties of new active substances as a basis for an adequate risk analysis and management in application of biocides. However, successful research and the availability of the complete dataset as required by BPR are cost and time intensive for applicants and set a high bar to engage into the approval process of an active substance.

Paint as well as adhesives’ manufacturers unanimously stated that there is no intrinsic motivation to use biocides *per se*. But options to completely avoid in-can preservatives in the final product were described as scarce, and in general they are combined with adverse side-effects. For example, silicate paints, which avoid biocides can only be used on mineral surfaces. Therefore, their use is technically restricted and due to their high pH (11.5) they also can cause skin or eye irritations.
Another option could be dry paint base materials, which have been reintroduced into the market recently. One paint manufacturer stated that they had dry paints on offer some 20 years ago but without economic success. It has to be seen whether the recent “revival” of this concept, which has the theoretical potential to eliminate in-can preservatives altogether, is successful.

Interview partners from industry as well as from workers' compensation boards also pointed to risks that would result from inadequate preservation. Besides technical deficiencies regarding product quality or appearance (odour, discolouring) there are also serious health risks from e.g., mould spores. One workers' compensation board argued that the risk of (mainly) dermal exposure by in-can preservatives is much easier to control than respiratory exposure by fungal spores.

There was general agreement that improved process hygiene is an important measure, although most measures that have been described in literature have already been implemented. But some manufacturers are still seeing potential to optimise their facilities and processes on this regard. But they also stated that even the most severe process hygiene does not allow for the avoidance of preservation measures in order to achieve the necessary shelf life of the end products. Some experts from the adhesive industry stressed that process hygiene at the client side in general poses a greater problem than process hygiene during production. Therefore, they have been starting to provide their clients with explicit hygiene guidelines.

7 Outlook

Reduction of volatile organic compounds in paints and adhesives has been a key issue of EU environmental regulations for the last decades. In order to maintain this the safe preservation of water-based products must be secured in the future.

This investigation showed that there is some leeway for optimisation with regard to measures of process and application hygiene, which can reduce the use of biocides. But there seems to be no denying the fact that a lack of applicable active substances for in-can preservatives of water-based paints and adhesives is discernible. Even though industry is developing new biocidal products, these are based upon the existing portfolio of approved active substances as there are virtually no research activities regarding new active substances for in-can preservatives.

Some experts argued that the bulk of potentially applicable substances has already been identified in the heyday of biocide research between the 1950s and 1970s. As a biocide by definition has to have some adverse properties it is not easy to find active substances that at the same time

- conform with current classification limits,
- show the necessary efficacy with regard to microorganisms and
- do not interfere with the relevant physico-chemical properties of the preserved products.

These challenges in combination with comparably low revenue expectations and – as seen by industry – relatively long-lasting approval processes pose the major obstacle to research.

Need for action is seen in improving and accelerating the approval process and to support research and development in this field. In order to maintain or even enlarge the use of solvent-free paints and adhesives it seems important to do all this without lowering protection standards of workers or product users.

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List of Abbreviations

AISE	International Association for Soaps, Detergents and Maintenance Products
APEO	Alkylphenolethoxylate
BAuA	Federal Institute for Occupational Safety and Health (BAuA)
BBIT	2-butyl-benzo[d]isothiazol-3-one
BIT	1,2-benzisothiazol-3(2H)-one
BG BAU	Employers' liability insurance association of construction industry
BPR	Biocidal Products Regulation (Regulation (EU) No 528/2012 of the European Parliament and of the Council of 22 May 2012 concerning the making available on the market and use of biocidal products)
CAS	Chemical Abstract Service
CEPE	European Council of the Paint, Printing Ink and Artists‘ Colours Industry
CLP	Regulation (EC) No. 1907/2006 of registration, evaluation and approval of substances or mixtures
CMC	Carboxymethylcellulose
CTAC	Methenamine 3-chloroallylochloride
DBNPA	2,2-dibromo-2-cyanoacetamide
DBDCB	2-bromo-2-(bromomethyl)pentanedinitrile
DDAC	Didecyldimethylammonium chloride (C8-10)
DGUV	Deutsche Gesetzliche Unfallversicherung (German Social Accident Insurance)
DMDMH	1,3-bis(hydroxymethyl)-5,5-dimethylimidazolidine-2,4-dione
DTBMA	2,2′-dithiobis[N-methylbenzamide]
EDHO	7a-ethyldihydro-1H,3H,5H-oxazolo[3,4-c]oxazole
EPDLA	European Polymer Dispersion and Latex Association
FEICA	Féderation Européenne des Industries de Colles et Adhésifs
HEC	Hydroxyethylcellulose
HHT	2,2′,2″-(hexahydro-1,3,5-triazine-1,3,5- triyl)triethanol
HPT	.alpha.,.alpha.′,.alpha.″-trimethyl-1,3,5-triazine-1,3,5(2H,4H,6H)-triethanol
IBC	Intermediate bulk containers
IBRG	International Biodeterioration Research Group
IPBC	3-iodo-2-propynylbutylcarbamate
IVDK	Informationsverbund Dermatologischer Kliniken (Information Network of Departments of Dermatology for the surveillance and scientific evaluation of contact allergies)

IVK	German Adhesives Association
MBM	N,N′-methylenebismorpholine
MHEC	Methylhydroxyethylcellulose
MIC	Minimum inhibitory concentration
MIT	2-methyl-2H-isothiazol-3-one
OPP	Biphenyl-2-ol
OIT	2-octyl-2H-isothiazol-3-one
PPE	Personal protective equipment
PHMB	polyhexamethylene biguanide hydrochloride
PU	Polyurethane
SCL	Specific Concentration Limit
TAED	tetra-acetylethylenediamine
THPS	Tetrakis(hydroxymethyl)phosphonium sulphate (2:1)
TMAD	Tetrahydro-1,3,4,6-tetrakis(hydroxymethyl)imidazo[4,5-d]imidazole-2,5 (1H,3H)-dione
VCI	German Association of Chemical Industry
VdL	German Association of Paint Producers
VOC	Volatile Organic Compounds

List of Substances

Substance name	CAS No.
Polyethoxyethanol	n/a
Ethoxylated tetramethyl decinediol (30 moles)	9014-85-1
Ethoxylated tetramethyl decinediol (10 moles)	9014-85-1
Nonylphenoxypoly (ethyleneoxy) ethanol A	9016-45-9
Sodium salt of alkylaryl polyether sulphate	n/a
Nonylphenoxypoly (ethyleneoxy) ethanol B	9016-45-9
Octylphenoxy polyethoxy ethanol	9036-19-5
Nonylphenoxypoly (ethyleneoxy) ethanol, wax	9016-45-9
Hydroxyethyl cellulose thickener A	9004-62-0
Hydroxyethyl cellulose thickener B	9004-62-0
Hydroxyethyl cellulose thickener C	9004-62-0
Polyvinyl alcohol A	9002-89-5
Polyvinyl alcohol B	9002-89-5
Cellulose ether (HEC, MHEC, CMC)	n/a
Titanium oxide	13463-67-7
Chlorocresol (CMK)	59-50-7
Glutaral (Glutaraldehyde)	111-30-8
N-(trichloromethylthio)phthalimide (Folpet)	133-07-3
Hydrogen peroxide	7722-84-1
3-iodo-2-propynylbutylcarbamate (IPBC)	55406-53-6
Peracetic acid	79-21-0
CMIT/MIT	55965-84-9
Biphenyl-2-ol (OPP)	90-43-7
N,N′-methylenebismorpholine (MBM)	5625-90-1
2-bromo-2-(bromomethyl)pentanedinitrile (DBDCB)	35691-65-7
2-octyl-2H-isothiazol-3-one (OIT)	26530-20-1
2-Phenoxyethanol	122-99-6
7a-ethyldihydro-1H,3H,5H-oxazolo[3,4-c]oxazole (EDHO)	7747-35-5
2-Brom-2-nitropropan-1,3-diol (Bronopol)	52-51-7
cis-1-(3-chloroallyl)-3,5,7-triaza-1- azoniaadamantane chloride (cis CTAC)	51229-78-8
Dodecylguanidine monohydrochloride	13590-97-1

Substance name	CAS No.
Ethanol	64-17-5
Monochloramine generated from ammonium carbamate and a chlorine source	n/a
Hexa-2,4-dienoic acid (Sorbic acid)	110-44-1
L-(+)-lactic acid	79-33-4
N-(3-aminopropyl)-N-dodecylpropane-1,3-diamine (Diamine)	2372-82-9
3,3′-methylenebis[5-methyloxazolidine] (Oxazolidine/MBO)	66204-44-2
p-[(diiodomethyl)sulphonyl]toluene	20018-09-1
Potassium (E,E)-hexa-2,4-dienoate (Potassium Sorbate)	24634-61-5
Pyrithione zinc (Zinc pyrithione)	13463-41-7
Didecyldimethylammonium chloride (DDAC (C8-10))	68424-95-3
(ethylenedioxy)dimethanol (Reaction products of ethylene glycol with paraformaldehyde (EGForm))	3586-55-8
Sodium 2-biphenylate	132-27-4
Pyridine-2-thiol 1-oxide, sodium salt (Sodium pyrithione)	3811-73-2
Tetrahydro-1,3,4,6-tetrakis(hydroxymethyl)imidazo[4,5-d]imidazole-2,5 (1H,3H)-dione (TMAD)	5395-50-6
Tetrakis(hydroxymethyl)phosphonium sulphate (2:1) (THPS)	55566-30-8
MBIT	2527-66-4
Methenamine 3-chloroallylochloride (CTAC)	4080-31-3
Reaction mass of titanium dioxide and silver chloride	
Sodium N-(hydroxymethyl)glycinate	70161-44-3
Peracetic acid generated from tetra-acetylethylenediamine (TAED) and sodium percarbonate	
PHMB (polyhexamethylene biguanide hydrochloride)	1802181-67-4
2-methyl-2H-isothiazol-3-one (MIT)	2682-20-4
2-butyl-benzo[d]isothiazol-3-one (BBIT)	4299-07-4
2,2-dibromo-2-cyanoacetamide (DBNPA)	10222-01-2
2,2′-dithiobis[N-methylbenzamide] (DTBMA)	2527-58-4
2,2′,2″-(hexahydro-1,3,5-triazine-1,3,5- triyl)triethanol (HHT)	4719-04-4
1,3-bis(hydroxymethyl)-5,5-dimethylimidazolidine-2,4-dione (DMDMH)	6440-58-0
1,2-benzisothiazol-3(2H)-one (BIT)	2634-33-5
.alpha.,.alpha.′,.alpha.″-trimethyl-1,3,5-triazine-1,3,5(2H,4H,6H)-triethanol (HPT)	25254-50-6
(benzyloxy)methanol	14548-60-8

Substance name	CAS No.
Didecyldimethylammonium chloride (DDAC)	7173-51-5
Tetrahydro-3,5-dimethyl-1,3,5-thiadiazine-2-thione (Dazomet)	533-74-4
Formic acid	64-18-6
2-Butanone, peroxide	1338-23-4
4,4-dimethyloxazolidine	51200-87-4
polyhexamethylene biguanide hydrochloride with a mean number-average molecular weight (Mn) of 1600 and a mean polydispersity (PDI) of 1.8 (PHMB(1600;1.8))	27083-27-8
Sodium pyrithione	15922-78-8
L-(+)-lactic acid	50-21-5
Potassium 2-biphenylate	13707-65-8
Sodium p-chloro-m-cresolate (Covered by chlorocresol)	15733-22-9
Quaternary ammonium compounds, di-C8-10- alkyldimethyl, chlorides	n/a
Silver chloride adsorbed to titanium dioxide (initially notified under silver chloride)	n/a
Silver chloride	7783-90-6
Methylchloroisothiazolinone / Methylisothiazolinone (MCIT/MIT)	n/a
Propolis	n/a
Formaldehyde	50-00-0
Quaternium 15	4080-31-3

Annex

Annex 1 Search results by keyword and database (English)

Keyword / Database	Greenfile	Open Dissertations	pubmed	Science Direct	Springer Link	Wiley
adhesive + biocide	0	1	541	1602	355	924
adhesive + preservative	0	1	37	3028	1402	36205
adhesive + storage	24	5	1395	32012	19387	67284
coating + biocide	20	7	290	3852	1187	1421
coating + preservative	3	1	54	5731	4261	48962
coating + storage	159	12	1675	86498	83321	130623
glue + biocide	1	1	50	547	175	410
glue + preservative	0	0	6	1340	864	8912
glue + storage	7	5	38	14025	16862	14324
in-can preservative	35	5	1	36329	192	349440
isothiazolinone	15	1	63	331	145	420
paint + biocide	31	1	155	1528	647	789
paint + preservative	2	1	22	1704	1641	22469
paint + storage	2	5	48	16884	34399	31008
preservatives for products during storage	110	80	286	11980	5350	99029
storage + biocide	8	3	817	3681	1029	1554

Annex 2 Search results by keyword and database (German)

Database Keyword	Science Direct	Springer Link	Wiley
Dispersionsfarbe + Biozid	0	5	4
Dispersionsfarbe + Konservierer	0	0	2
Farbe + Biozid	4	44	72
Farbe + Konservierer	0	0	23
Isothiazolinon	2	19	8
Klebstoff + Biozid	0	15	28
Klebstoff + Konservierer	1	0	4
Lack + Biozid	1	37	42
Lack + Konservierer	1	0	8
Topfkonservierer	0	6	1