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# Design of Stimuli-Responsive Dynamic Covalent Delivery Systems for Volatile Compounds (Part 2): Fragrance-Releasing Cleavable Surfactants in Functional Perfumery Applications

Vera Tchakalova,<sup>[a]</sup> Eric Lutz,<sup>[b]</sup> Serge Lamboley,<sup>[a]</sup> Emilie Moulin,<sup>[b]</sup> Daniel Benczédi,<sup>[a]</sup> Nicolas Giuseppone<sup>\*[b]</sup> and Andreas Herrmann<sup>\*[a]</sup>

Dedicated to the memory of Prof. François Diederich

**Abstract:** Amphiphilic imines prepared by condensation of a hydrophobic fragrance aldehyde with a hydrophilic amine derived from a hydrophilic poly(propylene oxide) and poly(ethylene oxide) diblock copolymer were investigated as cleavable surfactant profragrances in applications of functional perfumery. In water, the cleavable surfactants assemble into micelles that allow solubilization of perfume molecules that are not covalently attached to the surfactant. Dynamic headspace analysis on a glass surface showed that solubilized perfume molecules evaporated in a similar manner in the presence of the cleavable surfactant as compared with a non-cleavable reference surfactant. Under application conditions, the cleavable surfactant imine hydrolysed to release the covalently linked fragrance aldehyde. The profragrances were stable during storage in aqueous media and upon dilution showed a blooming effect for the hydrolytical fragrance release and a more balanced performance of a solubilized perfume by retaining the more volatile fragrances and boosting the evaporation of the less volatile fragrances.

## Introduction

Surfactants are key ingredients in common body and homecare formulations, such as personal care products, surface cleaners or fabric refreshers.<sup>[1]</sup> To fulfil the cleaning or softening function of these products, surfactants are used to help dissolve hydrophobic material in water and thus typically have a high affinity to various surfaces. Fragrances are added to these formulations to provide a pleasant smell in use.<sup>[2]</sup> Their presence, and in particular their location inside the micelles or at their interface,<sup>[3]</sup> influences the structure of the surfactant systems and thus the physico-chemical properties of the formulation.<sup>[4]</sup> For a long time, chemical stability of the surfactants over a wide range of pH was the key criterion for the development of surfactant systems. However, an increasing concern about the

impact of consumer products on the environment led to the design of cleavable surfactants,<sup>[5]</sup> which disintegrate after their use and thus increase the biocompatibility of these compounds.

On the other hand, the performance of perfumed body or homecare products is often judged on the long-lastingness of fragrance perception. Fragrances are highly volatile and thus rapidly evaporate after being applied to the target surface. One possibility for improving their long-lastingness, is to covalently link them to a suitable substrate to form a profragrance or properfume.<sup>[6,7]</sup> To release the fragrance in use, the covalent bond has to be cleaved under mild environmental conditions, e.g. by the action of heat, light or enzymes; by slow oxidation; or by hydrolysis that is possibly induced by a change of pH. In this context, reversible systems based on dynamic combinatorial/covalent chemistry have also been investigated.<sup>[7,8]</sup> Although the design of profragrances and of cleavable surfactants follow complementary needs, we wondered whether amphiphilic profragrances could fulfil a double role as a cleavable (co-)surfactant while at the same time providing a long-lasting fragrance perception as a profragrance. With fragrances being generally hydrophobic, they would constitute the hydrophobic part of a cleavable surfactant profragrance.

Cleavable amphiphiles based on dynamic covalent imine bond formation have been reported,<sup>[9]</sup> as have several profragrance systems that use imine bonds to release fragrances from various substrates.<sup>[10,11]</sup> Only a few systems suggest combining the advantage of disintegrating the amphiphilic properties of amphiphiles by covalent bond cleavage with the simultaneous release of a fragrance. For example, Matile and co-workers,<sup>[12]</sup> used amphiphiles formed by reversible hydrazide bond formation for the transmembrane transport of fragrances to simulate olfactory receptors, and Jiang and co-workers<sup>[13]</sup> reported amphiphilic poly(2-oxazoline)s to which fragrances were reversibly conjugated *via* imine bonds.

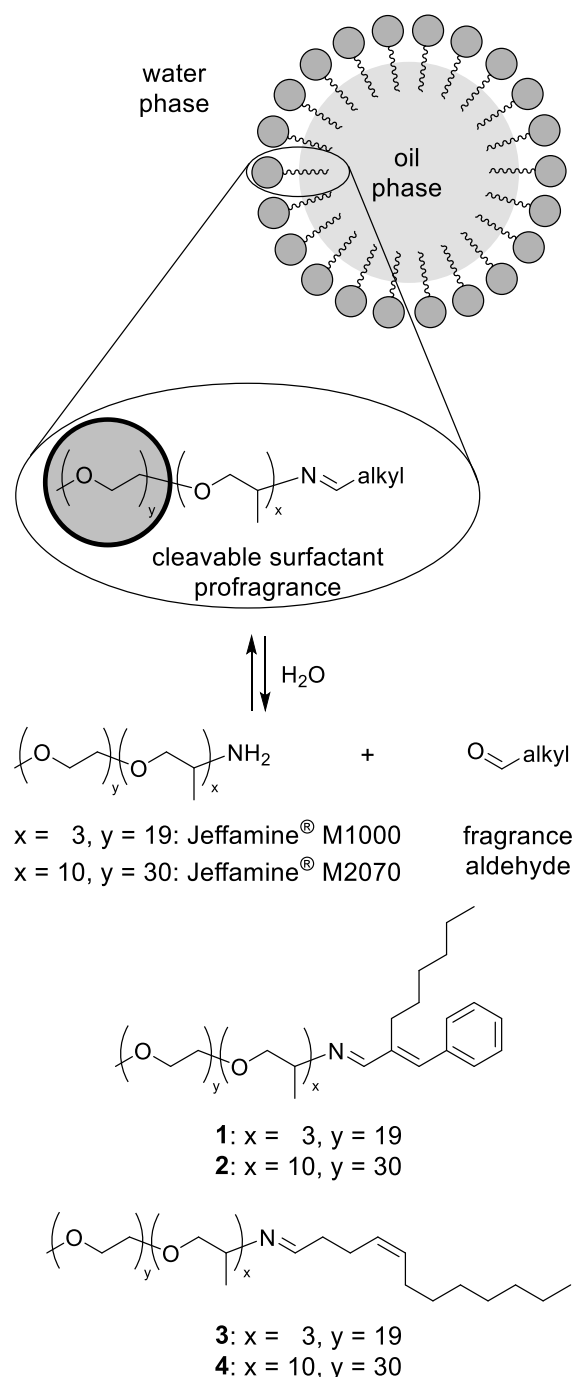
In our previous work, we have built dynamic imines connecting hydrophobic and hydrophilic moieties in order to generate dynamic covalent amphiphiles, which can protect their imine bonds from fast hydrolysis in water because of their self-assembly in various micellar structures.<sup>[14–16]</sup> In particular, in the preceding paper,<sup>[17]</sup> we showed that amphiphilic imines (e.g. 1–4, Scheme 1), obtained by condensation of a fragrance aldehyde as the hydrophobic part with an amine derived from a poly(propylene oxide) and poly(ethylene oxide) diblock copolymer of variable length (such as Jeffamines<sup>®</sup> M1000 and M2070) as the hydrophilic section have surfactant properties and self-assemble into micellar structures in water. We furthermore demonstrated that placing the hydrolytically labile

[a] Dr. V. Tchakalova, S. Lamboley, Dr. D. Benczédi, Dr. A. Herrmann  
Firmenich SA, Corporate R&D Division  
Rue de la Bergère 7  
CH-1242 Satigny, Switzerland  
E-mail: andreas.herrmann@firmenich.com;  
ORCID: 0000-0001-6997-3458

[b] Dr. E. Lutz, Dr. E. Moulin, Pr. Dr. N. Giuseppone  
SAMS research group  
Institut Charles Sadron, CNRS,  
University of Strasbourg, 23 rue du Loess, BP 84047,  
F-67034 Strasbourg Cedex 2, France  
E-mail: giuseppone@unistra.fr; ORCID: 0000-0003-4093-3000

Supporting information for this article is given via a link at the end of the document.

imine group within the hydrophobic part of the micelle, e.g. by using a linker between the labile imine group and the hydrophilic part of the amphiphile, resulted in relatively stable structures.<sup>[17]</sup> Similarly, in a different context, Smulders and co-workers<sup>[18]</sup> recently showed that the presence of polar domains in close proximity to the imine bond considerably accelerated the imine exchange within covalent adaptable networks.



**Scheme 1.** General concept of using cleavable surfactant profragrances for a stimuli-responsive long-lasting fragrance release and structures of hydrolytically cleavable imine profragrances 1–4 studied in the present work.

In the present study, we investigate whether amphiphilic imine profragrances can serve as surfactants to solubilize perfumes in an aqueous environment and thus be used as co-surfactants in formulations of functional perfumery and whether, upon an external stimulus, they disintegrate and release the fragrance that is covalently attached to the block copolymer.<sup>[19]</sup> Furthermore, we were interested to see whether different aspects of micelle formation of the cleavable surfactant imine also had a positive effect on the evaporation of co-solubilized (and non-covalently attached) perfume molecules.

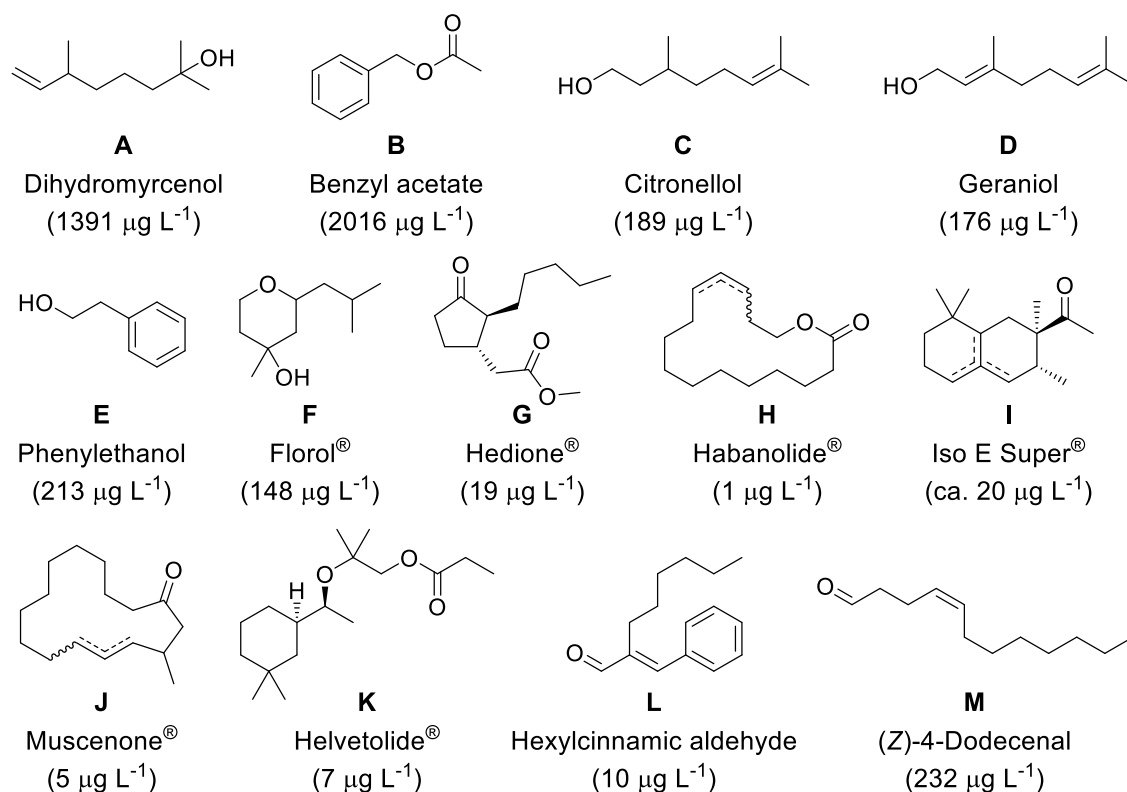
## Results and Discussion

### 1. Perfume solubilization and fragrance release from microemulsions – single-surfactant system

Cleavable surfactant imines 1–4 have calculated total hydrophilic-lipophilic balance (HLB(T)) values varying between 12.79 (2) and 13.64 (3) (Table 1), which are in the range of non-cleavable surfactants commonly used in functional perfumery.<sup>[17]</sup> As a first proof of concept to use cleavable imines as surfactants in practical applications, we determined the amount of 1–4 required for the solubilization of a typical model perfume in water. The model perfume was composed of perfumery ingredients A–K (Figure 1) in different amounts and dissolved in dipropylene glycol. This model perfume was then dispersed in water at an amount typically encountered in practical applications (3.3 wt%) to afford a turbid system. Imines 1–4 were then added individually under gentle agitation until transparent solutions were obtained. The formulations obtained after adding a minimum amount of surfactant to reach a transparent system are listed in Table 1, together with the resulting solubilization capacities of the profragrances, expressed as the molar ratio of perfume vs. surfactant. Higher solubilization capacities hereby correspond to lower surfactant concentrations required to solubilize a given amount of fragrance, i.e. to a higher perfume-to-surfactant ratio.

**Table 1.** Solubilization capacities and calculated HLB values of cleavable surfactant imine profragrances 1–4 in water.

Imine	Composition of transparent formulation [wt%] after adding a minimum amount of imine			Solubilizing capacity	HLB of imine
	Water	Perfume	Imine		
<b>1</b>	91.7	3.0	5.3	4.35	13.41
<b>2</b>	85.6	3.0	11.4	3.32	12.79
<b>3</b>	89.1	3.0	7.9	2.76	13.64
<b>4</b>	82.3	3.0	14.7	2.44	13.02



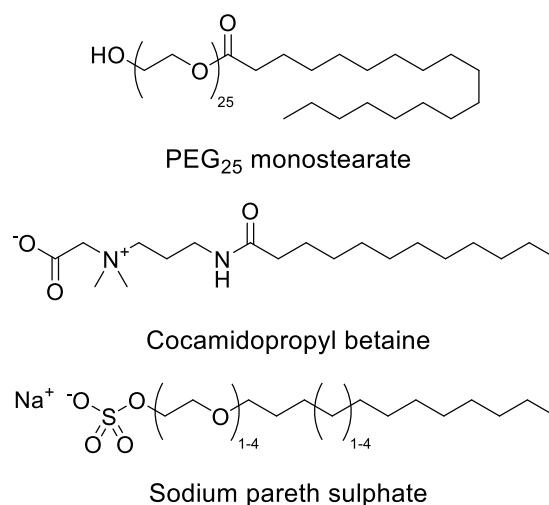
**Figure 1.** Structures and calculated volatilities (in parentheses) of perfumery ingredients **A–K** used in the model perfume and of fragrances **L** and **M** released from cleavable surfactant imines **1–4**.

All four cleavable profragrance imines allowed the solubilization of the perfume in water and thus acted as surfactants. From the data in Table 1, we can see that condensing the longer polypropylene oxide/polyethylene oxide diblock copolymer (Jeffamine<sup>®</sup> M2070) with a given fragrance resulted in a lower solubilizing capacity of the corresponding imine as compared with the imine obtained from the shorter block copolymer (Jeffamine<sup>®</sup> M1000). The HLB values of the imines containing the shorter block copolymer are also lower than those with the longer block copolymer. The shorter polar copolymer part of the surfactants leads to a lower critical micelle concentration (CMC) and a higher micelle quantity. The packing parameter, defined as  $v (a L)^{-1}$ , is a geometrical parameter indicating the micellar shape, with  $v$  being the hydrophobic volume,  $a$  being the area per molecule at the interface and  $L$  being the hydrophobic chain length. The higher the packing parameter, the more elongated are the micellar aggregates, allowing solubilization of a larger amount of oil. Thus, on one hand, decreasing the polar part of the surfactant by changing the length of the copolymer, diminishes the surface area and increases the packing parameter, leading to elongated micelles. On the other hand, the hydrophobic hexylcinnamyl moiety of surfactants **1** and **2** has a higher volume than does the dodecenylyl part of surfactants **3** and **4**, leading to a higher packing parameter as well. For these reasons, the surfactant containing the shorter copolymer and the hexylcinnamyl chain (**1**) demonstrated the highest solubilizing capacity of the present series.

To investigate the controlled release of the fragrances from the imines and their impact on the evaporation of the perfumery ingredients, we performed dynamic headspace measurements.<sup>[20]</sup> For our studies, we focused on imines **1** and **3** (with higher solubilization capacities) and compared their performance to that of a commercial non-cleavable surfactant (poly(ethylene glycol) (PEG)<sub>25</sub> monostearate, Figure 2).

Aqueous formulations containing imines **1** or **3** (7.9 wt%) and the model perfume (3.0 wt%) were prepared. A comparable formulation with PEG<sub>25</sub> monostearate (8.8 wt%) and perfume (2.9 wt%) was used as a reference. In all cases, homogeneous microemulsions were obtained, with an approximative surfactant concentration of 70 mM.

Aliquots of the different formulations were pipetted onto a watch glass and placed inside a dynamic headspace sampling cell.<sup>[21,22]</sup> A constant flow of air was passed through the system. The volatiles released into the air were trapped on poly(2,6-diphenyl-*p*-phenylene oxide) (Tenax<sup>®</sup> TA) cartridges at different time intervals. The clean cartridges were thermally desorbed and the recovered volatiles quantified by gas chromatography



**Figure 2.** Structures of commercially available non-ionic (PEG<sub>25</sub> monostearate), amphoteric (cocamidopropyl betaine) and anionic (sodium pareth sulphate) non-cleavable surfactants.

(GC). The GC method was adjusted to separate fragrances **A–K** from the model perfume together with fragrance aldehydes **L** and **M** (Figure 1) released from imines **1** and **3** by slow hydrolysis. The evaporation of all compounds in the mixture over time could thus be followed simultaneously in the same measurement.

Depending on the volatilities of the different fragrances,<sup>[23]</sup> two types of headspace curves were obtained. Headspace concentrations of compounds **A** and **B** with high volatilities (above  $1000 \mu\text{g L}^{-1}$ ) exponentially decreased during the measurement, while the concentrations of fragrances **C–F** with medium volatilities (between  $100$  and  $300 \mu\text{g L}^{-1}$ ) or **G–K** with low volatilities (below  $50 \mu\text{g L}^{-1}$ ) slightly increased at the beginning of the measurement before slowly decreasing again (medium volatilities) or reaching a plateau (low volatilities).

Figure 3 shows the headspace data recorded for fragrances **L** and **M**, which were released from cleavable imine surfactants **1** and **3**, and of fragrances **A**, **E**, **G** and **K** as representatives of the model perfume, with **M** and **E** ( $232$  and  $213 \mu\text{g L}^{-1}$ ) and **L** and **K** ( $10$  and  $7 \mu\text{g L}^{-1}$ ) having pairwise similar volatilities. The headspace concentrations for the other molecules of the model perfume, as well as the numerical data of the measurements, are reported in the Supporting Information (SI, Figure S1 and Tables S1–S3).

The headspace data showed that the fragrance evaporation of the model perfume in the presence of the two cleavable surfactants **1** and **3** is similar to that recorded in the presence of PEG<sub>25</sub> monostearate as the non-cleavable surfactant (reference). In some cases, especially for fragrances with medium volatilities (as for **C–F**), even slightly higher headspace concentrations were recorded in the presence of the cleavable surfactants as compared with the reference. Otherwise, the three systems are quite comparable. This indicates that the performance of cleavable surfactant imines **1** and **3** is similar to that of PEG<sub>25</sub> monostearate. However, when the water and the perfume

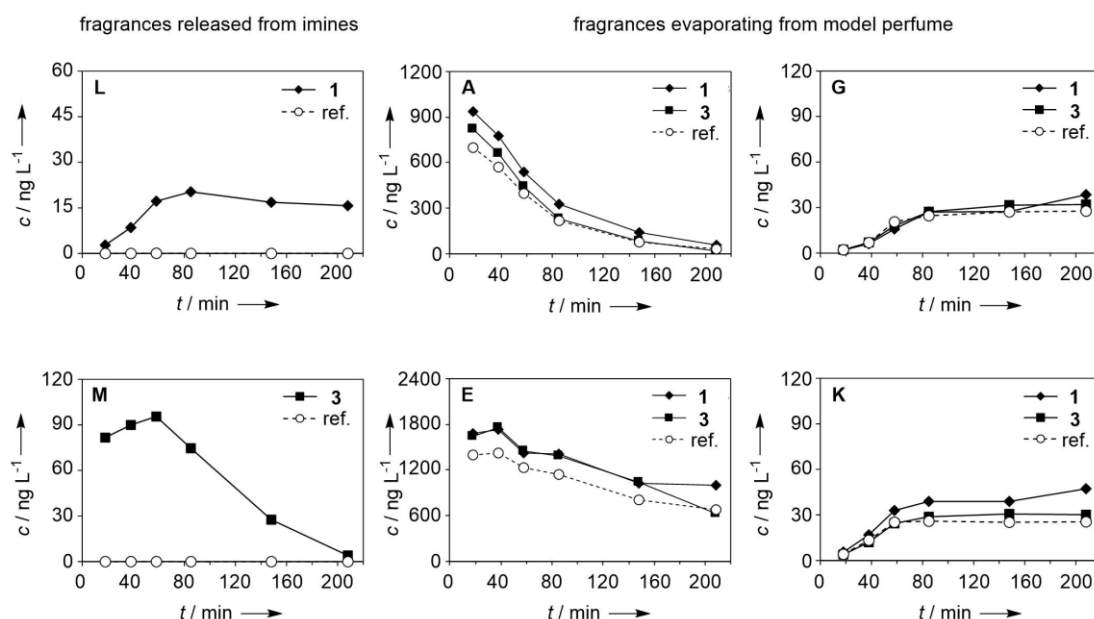
started to evaporate, rapid cleavage of the surfactant was observed with the release of **L** and **M** into the headspace, giving rise to boosting, or a so-called blooming effect. Furthermore, after a certain onset time, presumably due to the kinetics of the hydrolysis reaction, the shapes of the headspace curves of the released fragrances closely resembled those of non-conjugated free fragrance molecules with similar volatilities. It thus seems that cleavable surfactant profragrances have typical surfactant properties, namely solubilizing apolar fragrance molecules in water, at the same time delivering an additional fragrance material by cleavage of the imine bond during application.

## 2. Fragrance release from microemulsions – multiple-surfactant systems

Many applications in functional perfumery are aqueous-surfactant systems that require homogeneous formulations to be stable for several weeks at different temperatures. As it is demonstrated in Figure 3, the cleavable surfactants are rapidly hydrolysed, which might impact their use as a main surfactant for fragrance solubilization. They are thus ideally combined with another non-cleavable surfactant. For this reason, we investigated mixtures of cleavable surfactant imines **1** and **3** with other non-cleavable surfactants in specific ratios to stabilize the solubilizing system and to create controlled release properties.

In our preceding publication,<sup>[17]</sup> we showed that, at initial imine concentrations of ca.  $10 \text{ mM}$ , the cleavable imine surfactant rapidly hydrolysed in the presence of PEG<sub>25</sub> monostearate as the co-surfactant, but then reached stable equilibrium with a constant imine concentration (ca.  $4 \text{ mM}$ ). In the presence of other co-surfactants, continuous hydrolysis of the imine was observed. We thus chose PEG<sub>25</sub> monostearate as the co-surfactant for the present study.

In a first step, we replaced half the molar amount of imines **1** and **3** from the previous formulations with PEG<sub>25</sub> monostearate



**Figure 3.** Dynamic headspace concentrations of fragrances **L** and **M** released from cleavable surfactant imines **1** (—◆—) and **3** (—■—) and of fragrances **A**, **E**, **G** and **K** evaporating from the model perfume in the presence of **1** (—◆—) or **3** (—■—) on glass in a single-surfactant system. The corresponding data using PEG<sub>25</sub> monostearate (---○---) as a non-cleavable surfactant are given as the reference.



and used these 1:1 surfactant mixtures to solubilize the model perfume in water (Table 2). Again, as for the single-surfactant systems described earlier, homogeneous microemulsions were obtained.

**Table 2.** Compositions of microemulsions stabilized by a mixture of cleavable surfactant imines **1** and **3** and non-cleavable surfactant PEG<sub>25</sub> monostearate.

Composition	Mol fractions		
	F1	F2	Ref.
Water	0.9951	0.9951	0.9951
Model perfume	0.0037	0.0037	0.0036
Imine <b>1</b>	0.0006	0.0000	0.0000
Imine <b>3</b>	0.0000	0.0006	0.0000
PEG <sub>25</sub> monostearate	0.0006	0.0006	0.0013

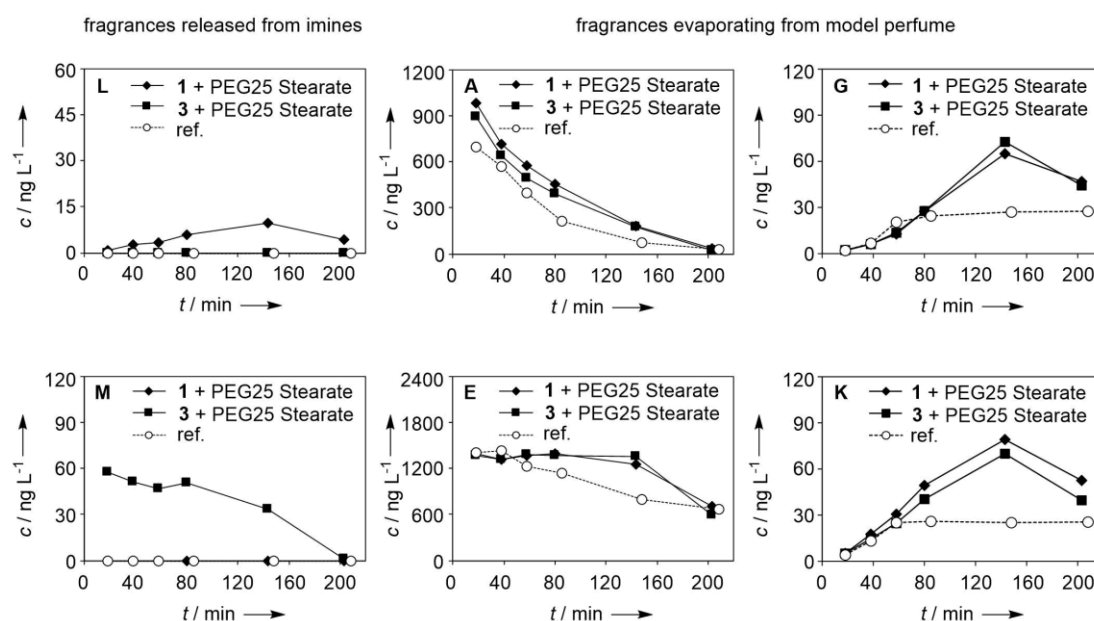
Aliquots of the mixed-surfactant systems were placed on a watch glass, and the evaporation of the fragrances was followed by dynamic headspace analysis as described earlier, with only slightly modified time intervals for sampling. Figure 4 shows the headspace data recorded for fragrances **L** and **M** released from **1** and **3** (in a mixture with PEG<sub>25</sub> monostearate) and of fragrance ingredients **A**, **E**, **G** and **K** as selected examples from the model perfume composition. For comparison, the previously recorded headspace data of the system with PEG<sub>25</sub> monostearate as the only surfactant was used as a reference. Headspace concentrations for the other fragrances and numerical data are listed in the SI (Figure S2 and Tables S4 and S5).

While for the single-surfactant system described earlier, where equivalent amounts of cleavable and non-cleavable surfactants gave similar results, this was no longer the case, if half the amount of the cleavable imine was replaced with a non-cleavable surfactant to form a binary-surfactant system. As

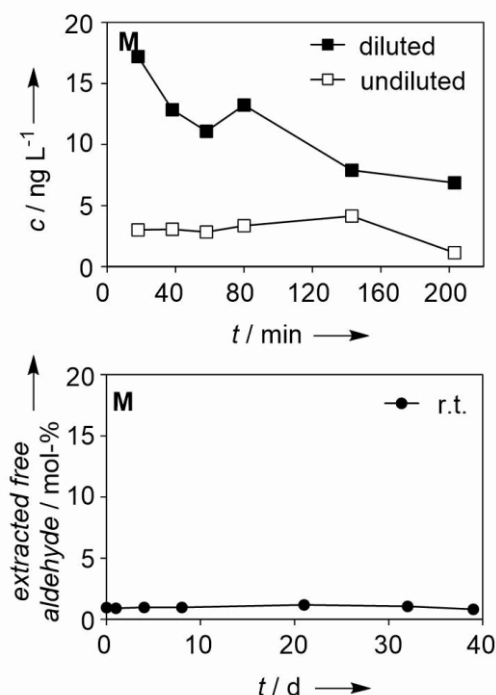
depicted in Figure 4, the release of the aldehydes as a result of the cleavage of the imines follows a similar pattern as that for the single-surfactant system, but with lower total amounts of fragrances being generated due to the smaller amount of imine used. However, the headspace concentrations of the fragrance ingredients that evaporated from the model fragrance showed a different trend in the binary systems, with considerably higher headspace concentrations being recorded between 70 to 200 min of sampling. Whereas in the previous experiment only slightly higher concentrations were measured for the fragrance ingredients with medium volatilities, this effect was now more pronounced and observed for all fragrance ingredients covering the entire range of volatilities. Using cleavable surfactant imines in a binary-surfactant system thus positively affects the evaporation of the model perfume, resulting in an increased boosting of perfume perception. Therefore, the binary mixture of cleavable and non-cleavable surfactant is advantageous compared with single surfactant systems by combining the storage stability of the consumer product with a blooming fragrance performance.

### 3. Fragrance release by dilution with water – multiple-surfactant systems

In our previous measurements, we showed that the presence of the cleavable surfactant boosted the headspace concentrations of the fragrance ingredients with different volatilities during the evaporation of water while generating an additional fragrance ingredient that was not present in the initial perfume composition. As the next step, we investigated the behaviour of the cleavable surfactant included in a typical shower gel formulation, which contained more than one surfactant in a relatively high concentration. Furthermore, we wondered how dilution with water, which is typical use of a shower gel application, would affect the cleavable surfactant and the fragrance release.



**Figure 4.** Dynamic headspace concentrations of fragrances **L** and **M** released from cleavable surfactant imines **1** (—◆—) and **3** (—■—) and of fragrances **A**, **E**, **G** and **K** evaporating from the model perfume in the presence of a 1:1 mixture of **1** (—◆—) or **3** (—■—) and PEG<sub>25</sub> monostearate on glass. The corresponding data using only PEG<sub>25</sub> monostearate (---○---) as a non-cleavable surfactant are given as the reference.



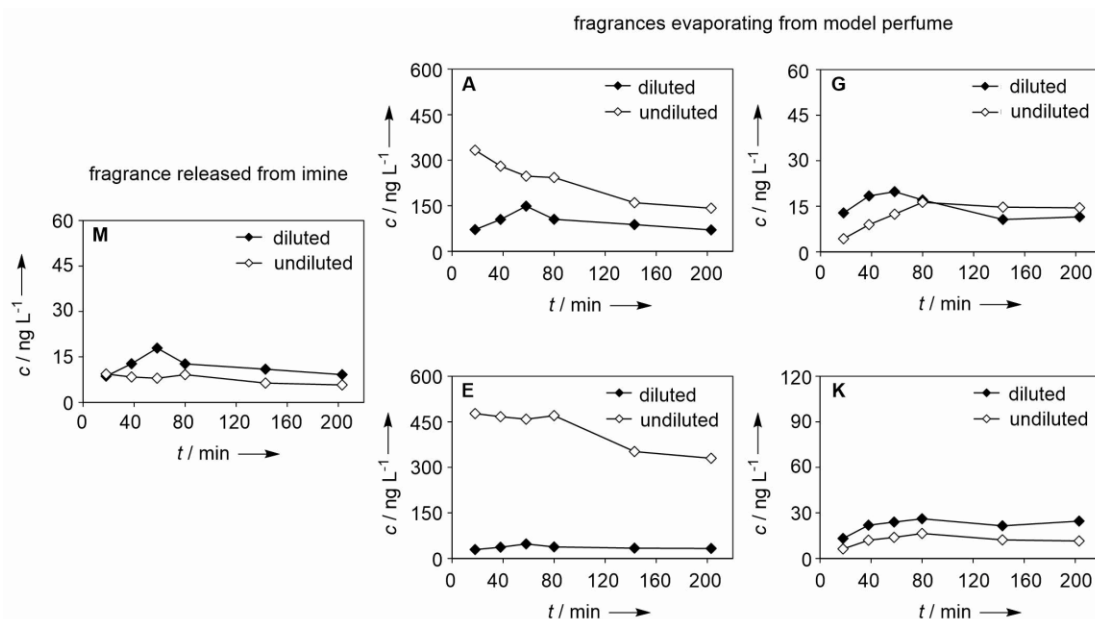
**Figure 5.** Dynamic headspace concentrations of fragrance **M** released from cleavable surfactant imine **3** in a model shower gel before (—□—) and after dilution (—■—) (top) and amounts of free aldehyde **M** extracted from imine **3** in the model shower gel during storage at room temperature (r.t., —●—) over 39 d (bottom).

As main active compounds, a model shower gel formulation contained an anionic surfactant (sodium parath sulphate, 27 wt%, Figure 2) and a betaine ester (cocamidobetaine) as an amphoteric surfactant (8 wt%). The total amount of water in the final formulation was 61.20 wt%. To this formulation (99.5 wt%),

cleavable surfactant imine **3** (0.5 wt%, corresponding to a surfactant imine concentration of ca. 4 mM) was added, and the release of the fragrance (**M**) was followed by dynamic headspace analysis as described earlier. Figure 5 (top) shows the data obtained for the different samples before dilution (undiluted) and after dilution with water (about 30 times).

Dilution triggered the release of the fragrance from the cleavable surfactant imine. Cleavage upon dilution is very fast and creates a blooming effect as an instant odour increase, which cannot be explained by simple fragrance diffusion.

To assess the stability of the cleavable surfactant imines in the shower gel, we stored the undiluted formulation containing cleavable surfactant **3** at room temperature for 39 days. At different time intervals, the amount of free (*Z*-4-dodecenal (**M**, released from **3**) was determined by GC after extraction of aliquots of the samples with *n*-heptane, using pentadecane as an internal standard. The extraction efficiency for (*Z*-4-dodecenal was determined in a model system by extracting a known amount of the aldehyde from the shower gel formulation. An average of 93% of **M** was extracted; this value was taken into account to adjust the amount of extracted free aldehydes in the stability test. Our measurements showed that the cleavable surfactant was stable in the undiluted shower gel formulations for 39 days at room temperature; an average of about 1 wt% of free **M** was extracted from the formulation after different time intervals (Figure 5, bottom). High storage stability is a key requirement for the use of any profragrance in perfumed consumer products. In particular for hydrolytically labile compounds this is usually difficult to achieve. In the present case, it seemed that the combination of embedding the labile imine function in the hydrophobic part of the micellar system and minimizing the amount of water in the concentrated initial formulation favoured the stability of the stimuli-responsive product. The initial total surfactant concentration in the gel was 35 wt%, which decreased to 1.2 wt% after dilution. Dilution increased the headspace concentration on average by a factor of 4.



**Figure 6.** Dynamic headspace concentrations of fragrances **A**, **E**, **G**, **K** and **M** evaporating from a freshly prepared diluted (—◆—) and undiluted (—◇—) shower gel formulation containing cleavable surfactant imine **3**.

As the next step, we added the model perfume to the shower gel formulation, using a composition containing 0.5 wt% of cleavable surfactant **3** and 0.5 wt% of the model perfume. The evaporation of the fragrances was followed by dynamic headspace sampling of a freshly prepared formulation before and after dilution. Figure 6 shows the headspace data for (*Z*)-4-dodecenal (**M**) released from the cleavable surfactant imine and of fragrances **A**, **E**, **G** and **K** representing different volatilities. Headspace concentrations for the other fragrances and numerical data are listed in the SI (Figure S3 and Tables S9 and S10).

Upon dilution, a slight boost of (*Z*)-4-dodecenal (**M**) released by hydrolysis from imine **3** was measured, as observed before in the absence of the model perfume. At the same time, upon dilution we recorded lower headspace concentrations for the more volatile fragrances **A** and **E** (with volatilities above 100  $\mu\text{g L}^{-1}$ ), while equivalent or slightly higher headspace concentrations were recorded for fragrances **G** and **K** with lower volatilities (below 50  $\mu\text{g L}^{-1}$ ). This resulted in a more balanced overall fragrance evaporation as compared to the undiluted reference.

Finally, we compared the headspace concentrations of our model perfume from a freshly prepared formulation with one that had been left standing at room temperature for 32 days after dilution (see Figure S4 in the SI). Our data showed similar release profiles for the evaporating fragrances from the freshly prepared and aged samples, thus demonstrating that the delivery system is stable during storage. In the aged sample (after standing for 32 days), even slightly higher headspace concentrations were tendentially recorded for several fragrances, although this difference is probably not sufficiently pronounced to observe a significant olfactive effect.

## Conclusion

Achieving a long-lasting and equilibrated fragrance perception is a difficult task with perfumes composed of highly volatile and rapidly evaporating ingredients, as well as those composed of substantive molecules with relatively low volatilities. Furthermore, with water being the most important solvent for most perfumery applications, the rather hydrophobic fragrances have to be efficiently solubilized in water-based formulations.

In our present work, we could demonstrate that micelle-forming cleavable surfactant imines, with the imine group being placed in the hydrophobic part of the micelle, are able to solubilize perfumes in an aqueous environment. The imine function turned out to be remarkably stable in water-based surfactant solutions. Dilution of concentrated aqueous formulations provoked an efficient and rapid hydrolysis of the imine and the release of an additional fragrance aldehyde, creating a blooming effect for that fragrance. The presence of the cleavable imine surfactant created a more balanced evaporation of solubilized perfume molecules after dilution by lowering the headspace concentrations for more volatile fragrances and increasing those for less volatile fragrances.

Cleavable surfactant profragrances can thus indeed fulfil a double role as a surfactant that readily splits into a hydrophobic fragrance aldehyde and a remaining hydrophilic block copolymer. Furthermore, the high storage stability of the present systems in aqueous formulations is a key advantage in view of the targeted practical applications in functional perfumery.

## Experimental Section

**General:** The preparation of cleavable surfactant imines **1–4** has been described in our previous report.<sup>[17]</sup>

**Dynamic headspace analysis:** Aliquots of the formulations containing the model perfume and surfactant formulations were pipetted onto a watch glass or into a crystallizing dish (in the case of the perfumed shower gel formulations), which were placed inside a homemade headspace sampling cell (ca. 625 mL inner volume). A constant flow of air (ca. 200 mL min<sup>-1</sup>) was aspirated through activated charcoal and a saturated solution of NaCl to ensure a constant humidity of the air of 75% before being passed through the headspace cell. The evaporating volatiles were adsorbed alternately onto waste (w) or clean (c) Tenax<sup>®</sup> cartridges, according to the following sequence: 15 min (w), 3 min (c), 17 min (w), 3 min (c), 12 min (w), 8 min (c), 19 min (w), 8 min (c), 53 min (w), 10 min (c), 50 min (w) and 10 min (c) (single-surfactant system); 15 min (w), 3 min (c), 17 min (w), 3 min (c), 17 min (w), 3 min (c), 17 min (w), 5 min (c), 55 min (w), 8 min (c), 52 min (w) and 8 min (c) (multi-surfactant systems and ethanol/water mixture). The waste cartridges were discarded, and the clean cartridges were thermally desorbed on a PerkinElmer TurboMatrix 350 thermodesorber, coupled to an Agilent 7890A gas chromatograph and connected to an Agilent 5975C mass spectrometer (MS). The volatiles were eluted on an HP-1 capillary column (30 m  $\times$  0.250 mm and a film thickness of 0.25  $\mu\text{m}$ ) at 100°C for 2 min, moving to 220°C at a rate of 5°C min<sup>-1</sup> and analysed by MS with single ion monitoring and time window programming. Quantifications were carried out by external standard calibration; ethanol solutions at different concentrations were directly injected onto clean Tenax<sup>®</sup> cartridges and processed under the same conditions. Because fragrances **A–M** were used at largely different concentrations, calibrations were carried out in two groups. Calibrations for mixtures of isomers were usually based on one of the isomers, mostly the major isomer present in the mixture. All measurements were carried out at least in duplicate. A total of six data points was thus collected during a total sampling time of 208 min or 203 min.

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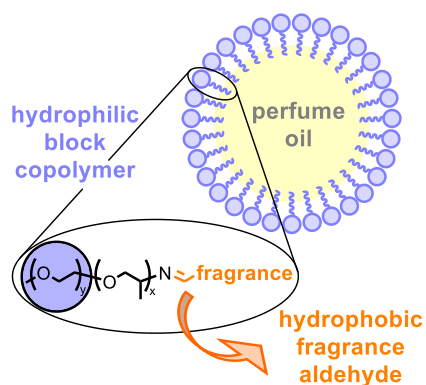
**Keywords:** amphiphiles / imines / micelles / perfume delivery / profragrances / surfactants

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## Entry for the Table of Contents



**Imine-based cleavable surfactant profragrances** assemble into micelles that allow solubilization of perfume molecules that are not covalently attached to the surfactant. Formulated systems were found to be stable during storage and released a fragrance aldehyde upon hydrolysis while providing a balanced evaporation of co-solubilized perfumery molecules.

Vera Tchakalova, Eric Lutz, Serge Lamboley, Emilie Moulin, Daniel Benczédi, Nicolas Giuseppone\* and Andreas Herrmann\*

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**Design of Stimuli-Responsive Dynamic Covalent Delivery Systems for Volatile Compounds (Part 2): Fragrance-Releasing Cleavable Surfactants in Functional Perfumery Applications**