LETTER

Supercritical carbon dioxide blackcurrant seed extract as an anti-irritant additive for hand dishwashing liquids

Tomasz Wasilewski, Artur Seweryn and Tomasz Bujak

aDepartment of Chemistry, Kazimierz Pulaski University of Technology and Humanities, Radom, Poland; bDepartment of Cosmetology, The University of Information Technology and Management, Tyczyn, Rzeszow, Poland

ABSTRACT

The study investigated the effect of hydrophobic, blackcurrant seed extract (Ribes nigrum L.) obtained under supercritical CO2 conditions on the anti-irritant properties of hand dishwashing liquids. A range of liquids differing in extract concentration (0–0.5 wt%) were prepared. The product prototypes were subjected to tests focusing on their anti-irritating property and functionality. Based on the zein values and measurements of changes in the pH level of the bovine albumin solution, the liquids were shown to be markedly safer to use. It was noted that an increase in extract concentration in a product leads to a deterioration of detergent and foaming properties. The highest concentration of the extract allowing the achievement of acceptable results was 0.3 wt%. The results suggest that hydrophobic plant extract, for example, from blackcurrant seed can be an interesting raw material for reducing the irritating potential of liquid agents designed for hand dishwashing.

ARTICLE HISTORY

Received 7 January 2016
Accepted 15 April 2016

KEYWORDS

Hand dishwashing liquid; supercritical CO2; Ribes nigrum L. extracts; quality; anti-irritant properties

Introduction

Hand dishwashing liquids (acronym HDLs) represent one of the most important groups of household chemicals. By assumption, the most significant function of products from this group is their detergent activity. However, they must also have a range of other attributes which facilitate their use, i.e. appropriate rheological and foaming properties, high efficiency, effective performance in hard water conditions, etc. (1–4). Regardless of properties related to their functionality, HDLs must also be safe to use. These considerations can be analyzed in several
aspects, including the effect on the skin of the hands and the surface of dishes during washing, impact on the natural environment or the possibility of HDL residues from improperly rinsed dish surfaces being transferred onto food and then into the human digestive system (1–4). Although raw materials used for manufacturing products of this type meet relevant requirements, the most challenging problem is the selection of HDL composition, so that the finished products would have a high detergent activity on the one hand, and makes the smallest possible negative impact on the skin of the hands on the other (1–5). Since the detergent activity and the effect on hand skin are – in this case – conflicting goals, HDL formulations must always represent some sort of a compromise.

HDLs are usually aqueous solutions of surfactants and various types of additives which are formulated in a specific way (1–4). The most common surfactants include alkyl aryl sulfonates, alkyl sulfonates, alkyl sulfates and alkyl ether sulfates. They are used due to their beneficial foaming properties, high washing power and easy modification of the viscosity of the product in which they are used (1–13). Auxiliary surfactants used in HDLs include mainly nonionic compounds (fatty alcohol ethoxylates, alkanolamides, alkyl polyglycosides) and amphoteric compounds (alkylamidopropyl betaines) (7–13). The primary role of auxiliary surfactants is usually to selectively improve specific product attributes related to both product functionality and safety of use (7, 11).

The basic ingredients of HDLs are surfactants (1, 4–6). The compounds ensure appropriate detergent and foaming properties, and make it possible to obtain an appropriate viscosity of finished products. A distinctive disadvantage of surfactants is that they can dry and irritate the skin of the hands. The adverse effect of surfactants on the skin is associated with the fact that in aqueous solutions the compounds, in addition to micelles, also occur in the form of individual molecules – the so-called monomers. The monomers interact with the skin, frequently contributing to skin irritation. Moreover, surfactants play a role in the removal of lipids from the outer skin layer, causing dryness and impairment of skin function as a protective barrier preventing the transfer of physical and chemical agents inside (4–6).

During the manufacture of HDLs, their compositions must be enriched with various additives to protect the skin of the hands. Additives used for that purpose comprise protein hydrolysates, polymers and special types of anionic (14), amphoteric or nonionic surface active agents (1–4). The presence of such additives typically lowers the critical micellization concentration, increases the size of micelles (hindering their penetration into the skin) and stabilizes them thermodynamically (reducing the number of micellar aggregate decompositions). The above processes entail a decrease in monomer concentration in the solution, which reduces the potential for skin irritation (6–13).

Another interesting solution aimed at limiting the negative effect of HDLs on the skin of the hands is providing the composition with hydrophobic substances, e.g. plant oils, lanolin or oils of mineral origin (15–18). Other additives which are popular with HDL users are hydrophobic active substances derived from plants. However, the process of their isolation requires steam distillation or extraction with organic solvents (e.g. ethyl alcohol or propylene glycol). In the former case, high temperatures often lead to the decomposition of active substances. In contrast, solvent-based extraction means that solvents are present in the raw material that is introduced into the product. It is a major problem considering the safety of use of such products. Also, it often increases the price of the raw material. Another aspect is that solvents which remain in the product may have an adverse impact on its functional profile, e.g. impair the foaming properties (1, 2, 19).

An alternative to solvent extracts is the enrichment of HDL formulations with extracts obtained using carbon dioxide (CO2) in the supercritical state. An enormous advantage of this extraction method is the relatively low temperature of the process, which makes it possible to retain the majority of valuable active substances in the extracts and eliminates the solvent (on completion of the process, CO2 is removed from the raw material) (21, 22, 24).

Supercritical carbon dioxide blackcurrant seed extract is a source of triglycerides (23–25) and many active ingredients (26). It contains a significant amount of tocopherols (γ-tocopherol, α-tocopherol), tococtrienols, and it is a natural source of α-linolenic acid (ALA). The oil of black currant seeds belongs to the group of oils richest in γ-linolenic acid (GLA), ALA and stearidonic acid (23–25). Such a combination of fatty acids is not found in any other oil (23). The chemical composition of blackcurrant seed extract obtained by the following operational conditions (350 bar, 50°C, and flow rate of CO2 0.4 L/min) was analogous to that one reported by Yang et al. (25) (Tables 1 and 2).

The present paper reports results of studies investigating the formulation of HDLs containing a hydrophobic extract derived from blackcurrant seeds by means of supercritical CO2 extraction. A detailed analysis was conducted for parameters related to the skin irritation potential (safety of use). However, introduction of hydrophobic extract to the formulary cannot significantly affect the deterioration of performance.
parameters. Therefore, tests related to functional properties of prepared formulations were also carried out.

Materials and methods

Materials

Raw materials used in the commercial household products industry were utilized to develop HDLs: sodium laureth sulfate (Texapon NSO; BASF, Ludwigshafen, Germany), cocamidopropyl betaine (Dehyton K; BASF, Ludwigshafen, Germany), laureth-7 (PCC Rokita SA, Brzeg Dolny, Poland), PEG-40 hydrogenated castor oil (Emulsionante ELH40, Erca, Poland), *Ribes nigrum* seed oil – extract obtained at supercritical conditions of CO2 (New Chemical Syntheses Institute, Puławy, Poland), citric acid (Breentag, Poland), sodium chloride (NaCl; POCH, Gliwice, Poland), methylchloroisothiazolinone and methylisothiazolinone as preservatives (Euxyl K120; Schulke & Mayr, Fairfield, NJ), distilled water.

Preparation of HDLs

The development of HDL formulations containing hydrophobic extracts requires using an appropriate type of surfactants which retain good detergent activity in the presence of hydrophobic substances. Based on experiences to date and literature reports (1–4), a formulation containing sodium laureth sulfate as the basic ingredient was proposed. The surfactant composition was enriched with cocamidopropyl betaine, which is commonly used mainly due to a reduction of the irritation potential of sodium laureth sulfate (1, 7–10). Laureth-7 was used as a surfactant improving the washing properties and the ability to emulsify fatty soiling (1, 2). PEG-40 hydrogenated castor oil was also included as a surfactant exhibiting high solubilization ability. A variety of auxiliary substances were also added to product compositions, including sodium chloride (viscosity modifier), mixture of methylchloroisothiazolinone and methylisothiazolinone (preservative) and citric acid (pH regulator). The formulations of the liquids are shown in Table 3.

Three products were developed, differing in the content of the blackcurrant seed extract. The extract concentrations were 0.1, 0.3 and 0.5 wt% (designated as HDL_0.1, HDL_0.3 and HDL_0.5, respectively). The point of reference was a control sample having an analogous formulation but not containing any extract (designated as HDL_0).

The production of the extract-containing products required an appropriate procedure. As the first step, the extract of blackcurrant seeds was mixed with PEG-40 hydrogenated castor oil so that it would be possible to thoroughly solubilize the hydrophobic extract in subsequent stages. The process of mixing both ingredients was carried out at the temperature of 40°C. The remaining ingredients were mixed with water at room temperature. Next, a mixture of a plant extract with a solubilizer was added and the entire contents were mixed thoroughly. The products thus obtained were clear and stable for a minimum of three months.

Methods

Determination of irritant potential – the zein value

Irritant potential of the products was measured using the zein test. In the surfactants’ solution, zein protein is denatured and then solubilized in the solution. This process simulates the behavior of surfactants in relation to the skin proteins (14, 27).

Zein (2 ± 0.05 g) from corn was added to 40 mL of HDLs solution (10 wt%). The solutions with zein was shaken on a shaker with water bath (60 min at 35°C).

| Component (INCI name) | HDL_0 | HDL_0.1 | HDL_0.3 | HDL_0.5 |
|-----------------------|-------|---------|---------|---------|
| Aqua                  | ad    | 100     |         |         |
| Sodium laureth sulfate| 9.0   |         |         |         |
| Cocamidopropyl betaine| 1.0  |         |         |         |
| Laureth-7             | 2.0   |         |         |         |
| PEG-40 hydrogenated castor oil | 1.7 | 0       | 0.1     | 0.3     | 0.5     |
| *Ribes nigrum* seed oil |     |         |         |         |
| Citric acid           | 0.3   |         |         |         |
| Sodium chloride       | 3.5   |         |         |         |
| Preservative          | 0.2   |         |         |         |

Note: International Nomenclature of Cosmetic Ingredients (INCI).
The solution was filtered using Whatman No. 1 filter paper and then centrifuged at 5000 rpm for 10 min. The nitrogen content in the solutions was determined by the Kjeldahl method. One millilitre of the filtrate was mineralized in a sulfuric acid (98%) containing copper sulfate pentahydrate and potassium sulfate. After mineralization, the solution was transferred (with 50 mL of MilliQ water) into the flask of the Wagner–Parnas apparatus, and 20 mL of sodium hydroxide (25 wt%) was added to that solution. The ammonia released was distilled with steam. Then the ammonia was bound by sulfuric acid (5 mL of 0.1 N H₂SO₄) in the receiver of the Wagner–Parnas apparatus. The unbound sulfuric acid was titrated with 0.1 N sodium hydroxide. Tashiro mean of three independent measurements. For titration of the sample. The

\[ \text{ZN} = (10 - V_f) \cdot 100 \cdot 0.7 \text{ mg N/100 mL}, \]

where \( V_f \) is the volume (cm³) of sodium hydroxide used for titration of the sample. The final result was the arithmetic mean of three independent measurements.

**Determination of irritant potential – pH rise test with bovine serum albumin**

Fifty gram of aqueous solution of bovine serum albumin (BSA) (2 wt%, pH = 5.5) was mixed with 50 g of HDLs solution (10 wt%, pH = 5.5). pH of the BSA and analyzed samples solution was regulated with the sodium hydroxide or citric acid solutions. Samples were stirred (200 rpm, 3 h). After 72 h incubation at room temperature, pH was measured (pH-meter Elmetron, 22°C). The final result was the arithmetic mean of five independent measurements. The result was presented as the difference in pH of the solution after incubation and pH of solution before incubation (value 5.5).

**Viscosity measurements**

A Brookfield RV DVIII+ rheometer was used. Measurements were carried out at 22°C with a rotary speed of the spindle of 10 rpm. Viscosity values presented in the figures represent average values obtained from five independent measurements.

**Evaluation of the ability to emulsify fatty soils by studied liquids**

The procedure is in line with Polish Standard PN-C-577003. The maximum weight of rapeseed oil colored with Sudan Red (0.1 g of Sudan IV per 1000 mL of rapeseed oil) capable of being emulsified by 1 dm³ of a 1% aqueous solution of the studied HDLs was determined. The experiments were carried out as follows: 1.4 g of rapeseed oil colored with Sudan Red (model fatty soil) and 2.0 g of the studied HDL were placed in a 50 mL beaker. Then the mixture was intensively stirred with a glass rod (diameter of the rod, 7 mm; rotational speed, about 200 rpm) for 5 min. The mixture obtained was transferred quantitatively into a 200 cm³ volumetric flask and brought up to volume with distilled water. The flask was closed and rotated for 5 min with rotations of 180° (one rotation per second). The resulting emulsion was placed in an incubator (45°C) for 30 min. The flask was then taken out, and the emulsion was assessed. Separation of the oil layer in the flask’s neck or the appearance of one or more drops of colored oil in the upper part of the flask’s neck was considered to be a negative result (the liquid was not capable of emulsifying a given weight of fatty soil). When a negative result was obtained, subsequent trials were carried out in which the weight of oil was decreased by 0.2 g. If the result obtained was then positive, subsequent trials were carried out (with an increase in the oil weight of 0.2 g) until a negative result was obtained. The final result of the ability to emulsify fatty soil by the studied HDL was given as grams of oil per 1 L of 1% HDL solution.

**Evaluation of the foaming properties**

The method of measurement was in line with Polish Standard PN-EN 1272. The experiments were carried out as follows: 100 cm³ of a 1% aqueous solution of the studied HDL was poured into a glass cylinder. Then, the foam was whipped (time of whipping, 60 s; number of full hits, 60) using a perforated disk placed on a metal bar. The volume of the foam formed was read out after 10 s. The ability to form foam was analyzed as the volume of the foam formed registered 10 s after its creation. Additionally the percent foam stability coefficient was evaluated as the ratio of the foam volume after 10 min to the volume after 1 min. The final result was the arithmetic mean of three independent measurements.

**Assessment of detergent properties**

The study was conducted in accordance with the methodology proposed by Industrieverband Körperpflege Und Waschmittel (IKW – The German Cosmetic, Toiletry, Perfumery and Detergent Association) (20). The study involves an assessment of detergent properties of HDLs, a measure of which is the dissipation of foam in the washing bath. To perform the test, a standard high-fat soil formulation is used (composition: pork lard 4.7%, rapeseed oil 4.7%, sunflower oil 4.7%, margarine 4.7%, olive oil 4.7%, milk powder 4.7%, 30% cream 4.7%, butter 4.7%, flour 18.8%, water with a hardness level of 16°d, C.I. reactive red 180 dye 0.2%). According to the method, test dinner plates soiled with the standard formulation are washed in the washing bath.
obtained by pouring 5 L of water at a temperature of 45° C from a height of 1 m into a small polyethylene tub with
the test product applied at the bottom. The plates are
washed until the dissipation of foam in the washing
bath. The test result is equivalent to the number of
plates washed until the complete dissipation of foam
in the washing bath. The final test result is an arithmetic
mean of three separate tests.

Statistical analysis
The points in the charts represent mean values from a
series of three or five independent measurements. The
Student’s t-distribution was used to calculate confidence
limits for the mean values. Confidence intervals, which
constitute a measuring error, were determined for the
confidence level of 0.90. Error values are presented in
the figures.

Results and discussion

Skin irritation potential of HDLs

Parameters associated with the products’ safety of use
were verified by determining the ZN (Figure 1) and
applying a method which comprised measurements of
changes in the pH of a BSA solution (Figure 2) developed
by Imokawa et al. (28) and Tavss et al. (29).

Zein value

The results of zein value determinations for the studied
group of products are shown in Figure 1.

One of the mechanisms underlying the skin-irritating
activity of surfactants is associated with the binding and
denaturation of epidermal proteins by surfactant mol-
ecules (14, 30, 31). The literature data indicate that the
skin-irritating activity is largely attributable to surfactant
monomers. Above the critical micelle concentration
(CMC), micelles start forming in the solution, and the
number of ‘free’ monomers is markedly reduced. Further-
more, the most potent skin-irritating activity is exhibited
by anionic surfactants that could get bound to proteins
via strong electrostatic bonds. The irritant potential of
washing products can be assessed by the zein test,
which is based on zein, a water-insoluble protein found
in corn. In a solution of surfactants, zein undergoes dena-
turation and then solubilization in the solution. The more
protein is solubilized (as determined by analyzing the
nitrogen content in a sample), the greater the irritant
potential of a washing formulation (14, 30, 31).

The value of the ZN is a type of measure of the irritant
potential of liquids with respect to the skin of the hands.
The values obtained for the formulated products varied
in the range of 150–190 mg N/100 mL. The highest
value of the ZN, 196 units, was noted for the product
which did not contain any plant extract. A decrease in
the determined value by around 13% and 15% in relation
to the reference product was noted for the products con-
taining 0.1% and 0.3% of the extract, respectively. By far
the greatest decrease in the value of the ZN was
recorded for the formulation containing 0.5% of the
extract. The result was 152 mg N/100 mL and was thus
nearly 22% lower than in the control sample. The
values obtained for samples containing extract were stat-
istically significantly different in relation to the control
sample. The results demonstrate that addition of a
hydrophobic extract of blackcurrant seeds to HDLs con-
tributes to a reduction of their potential for irritation of
the skin of the hands. The literature data (14, 28–33)
show that the skin-irritating activity is mainly attribut-
able to surfactant monomers. Above the CMC, micelles start
forming in the solution, and the number of ‘free’ mono-
mers is markedly reduced. An addition of a hydrophobic
phase causes its incorporation into the micelle structure,
producing an increase in aggregate size (through hinder-
ing their penetration into the protein structure) and their
stability by increasing the distance between the hydro-
philic heads of surfactant molecules and reducing the
forces of mutual repulsion (28–33).

pH rise test with BSA

The results of the zein test were verified using the
method developed by Imokawa et al. (28) and Tavss
et al. (29), based on measuring changes in the pH of a
BSA solution. The contact of water-soluble BSA with
anionic surfactant solutions leads to the neutralization
of cationic protein groups by anionic surfactants. A con-
sequence of the process is the adsorption of protons
from water by negatively charged BSA groups. The
process leads to an increase in the pH of the solution.
The higher the increase in the pH level, the greater the
skin-irritating activity of surfactants. The measurement
results are shown in Figure 2.

The results corroborate the outcomes of the zein test.
The highest pH increase, by around 1.2 units, was noted

Figure 1. Zein volume of HDLs.
for the control sample. An addition of a blackcurrant extract to HDL formulations contributes to a reduction in the value of the analyzed parameter. An increase in the concentration of the extract in the formulation was found to be accompanied by a lower increase in the pH of the BSA solution. Adding the extract at the concentration of 0.1 wt% was followed by a 10% lower pH increase (by around 1.1 pH units). At the concentration of 0.5 wt%, however, the increase in the pH of the solution was ca. 20% lower than in the baseline sample. The results demonstrate that adding a hydrophobic extract to HDL formulations reduces their skin-irritating activity.

**Functionality of HDLs**

**Dynamic viscosity**

Viscosity is one of the fundamental parameters receiving special attention in the process of developing formulations for HDLs. Appropriately high viscosity levels enable the consumer to control the dosing of the product. On the other hand, however, it needs to be noted that an excessively high viscosity of the product may contribute to an insufficiently fast rate of dissolution in water and, consequently, incomplete utilization of the dose of the product during dishwashing (3).

Adding a hydrophobic extract to the formulation influences a change in the size and shape of surfactant aggregates (15, 16, 34). The decisive factors determining the viscosity and appearance of the system are the concentration and hydrophobicity of the extract, and the presence of electrolytes (1, 2). All the studied products were provided with a constant sodium chloride content of 3.5%. The only variable differentiating the products was the concentration of the extract of blackcurrent seeds obtained under supercritical CO2 conditions. The viscosity values of the formulated model HDLs are shown in Figure 3.

An increase in the concentration of the plant extract was shown to be accompanied by a decrease in dynamic viscosity. The results are consistent with the literature data (15, 16, 34) indicating that the presence of hydrophobic substances in an aqueous solution of surface active agents contributes to a considerable change of ordering in the volume phase of the product. For products containing 0.1% and 0.3% of the extract, respectively, the decrease in viscosity in comparison to the product not containing any extract was relatively small, not exceeding 15%. A 0.5% addition of the extract induced a very sharp drop in viscosity: the values of the measured parameter were found to be over 65% lower than in the reference formulation. The findings show that the addition of the extract at such a high concentration does not guarantee obtaining a product characterized by the required functionality.

**Ability to emulsify fatty soils**

The ability of the product to transform fatty soiling (vegetable or animal oils used in the household) into a stable dispersion is particularly important from the viewpoint of preventing the redeposition of soiling during the process of dishwashing. It also contributes to an improvement in effectiveness. The results obtained for the formulated liquids are shown in Figure 4.

An increase in the concentration of the plant extract used in the formulations was also found to be correlated with a slight decrease in emulsification ability. The highest result (20.2 g/L) was achieved for the product which did not contain any plant extract. The least favorable profile of emulsifying fatty soiling (approximately
16.4 g/L) was recorded for the formulation containing 0.5% of the extract. The results conform to expectations. The extract added to the products demonstrates high hydrophobicity. Therefore, it is obvious that a part of the surfactants contained in the product will be ‘used up’ for its solubilization. The results obtained in the study corroborate these assumptions. An increase in the proportion of the extract contributed to a decrease in the detergent activity of the products against fatty soiling.

**Foaming properties**
The results of studies on the foam ability properties of HDLs are shown in Figure 5.

An increase in the concentration of the blackcurrant seed extract in the HDL formulation was shown to be accompanied by a decrease in foam volume. The highest foaming ability, approximately 570 cm³, was noted for the product which did not contain any plant extract. A slight decrease in foaming-ability levels, amounting to around 15% in relation to the reference product, was observed for the liquids containing 0.1% and 0.3% of the extract. The formulation containing 0.5% of the extract was found to have by far the least favorable foaming properties. The foaming ability of the product was 260 cm³ and was thus nearly 40% lower than in the reference formulation.

The products were also analyzed to determine the values of their foam stability index. A 0.3% addition of the extract had practically no effect on reducing foam stability. It was only with the 0.5% addition of the extract that a noticeable drop in the measured parameter (by ca. 17%) was identified.

**Detergency**
The results of studies on the detergency properties of HDLs are shown in Figure 6.

An increase in the concentration of the blackcurrant seed extract in the HDL formulation was shown to be accompanied by a decrease in the value of the studied parameter. The highest result in the study, amounting to 25 washed plates, was achieved for the product which did not contain any plant extract. A slight decrease in the value of the parameter, amounting to around 2–5 units compared to the reference product, was observed for the liquids containing 0.1% and 0.3% of the extract. The least favorable detergent properties were observed for the formulation containing 0.5% of the extract. The value obtained in the study for the product was 17 washed plates and was nearly 30% lower than in the reference formulation.

**Conclusions**
The study investigated the effect of a plant extract (made of blackcurrant seeds) obtained under supercritical CO₂ conditions on selected properties of HDLs. The assessment comprised the basic properties of this product group. The results obtained in the study show that the blackcurrant seed extract has a significant effect on the anti-irritant and functional properties of HDLs. Addition of the extract to HDLs significantly affects the safety of product use. The results of ZN determination point showed a 30% decrease in the skin-irritating potential for the 0.5 wt% content of the extract. The results are consistent with the outcomes of tests investigating the pH increase of a BSA solution subjected to a contact with the analyzed HDLs. After using the extract at the concentration of 0.5 wt%, the pH increase in relation to the baseline sample was ca. 20% lower. The presence of the extract influences the viscosity of the formulation: an increase in the proportion of the extract in the formulation causes a decrease in product viscosity. An increase in the concentration of the blackcurrant seed extract contributes to a slight deterioration of the emulsification properties of products. The obtained HDLs exhibit a high foaming ability; however an increase in the content of the additive has an effect on the deterioration of the foaming ability. An increase in the concentration of the blackcurrant seed extract contributes to a deterioration of the detergent properties of HDLs.

The results obtained in the study show that an addition of the extract at concentrations exceeding...
0.3% leads to a noticeable deterioration in the functional properties of products. Nevertheless, it must be stressed that the ability to improve the safety of use of the analyzed product group makes extracts obtained under supercritical CO₂ conditions a potentially very attractive group of raw materials, which make it possible to enhance the quality of HDLs.

**Disclosure statement**

No potential conflict of interest was reported by the authors.

**Funding**

This work was supported by National Centre for Research and Development [grant number PBS1/A5/18/2012].

**References**

(1) Gambogi, J.; Arvanitidou, E.S.; Lai, K. Light-duty Liquid Detergents. In *Liquid Detergents, 2nd ed.*; Schick, M., Eds.; Taylor & Francis Group: Boca Raton, FL, 2006; pp 171–238.
(2) Shi, J.; Scheper, W.M.; Sivik, M.R.; Jordan, G.T.; Bodet, J.; Song, B.X. Dishwashing Detergents. In *Handbook of Detergents Part D; Formulation,* Showel, M.S., Eds.; CRC Press, Taylor & Francis Group; Boca Raton, FL, 2006; pp 105–152.
(3) Wasilewski, T.J. *Surf. Deterg.* 2010, 13, 513–520.
(4) Wasilewski, T.; Bujak, T. *Ind. Eng. Chem. Res.* 2014, 53, 13356–13361.
(5) Bujak, T.; Wasilewski, T.; Nizioł-Lukaszewska, Z. *Colloids Surf. B* 2015, 135, 497–503.
(6) Cohen, L.; Soto, F.; Luna, M.S. *J. Surf. Deterg.* 2001, 4, 147–150.
(7) Tamura, T.; Iiharab, T.; Nishidab, S.; Ohtab, S. *J. Surf. Deterg.* 1999, 2, 207–211.
(8) Takeda, M.; Kurihara, M.; Shibuya, S.; Kitamura, K.; Matsumoto, A.; Moriya, M.; Hidaka, H. *J. Jpn. Oil Chem. Soc.* 1996, 45, 1239–1246.
(9) Iwasaki, T.; Ogawa, M.; Esumi, K.; Megro, K. *Langmuir* 1990, 7, 30–35.
(10) Tamura, T.; Kaneko, Y.; Ohyama, M. *J. Colloid Interface Sci.* 1995, 173, 493–499.
(11) Bozetine, I.; Zai, T.; Chitour, C.E.; Canselier, J.P. *J. Surf. Deterg.* 2008, 11, 299–305.
(12) Andree, H.; Middelhauve, B. *Tenside Surf. Deterg.* 1991, 28, 413–418.
(13) Nieendick, C.; Schmid, K.H. *Jornadas Comite Esp Detergencia.* 1995, 26, 63–67.
(14) Cohen, L.; Martin, M.; Soto, F.; Trujillo, F.; Sanchez, E. *J. Surf. Deterg.* 2016, 19, 219–222.
(15) Tehrani-Bagha, A.; Holmberg, K. *Materials* 2013, 6, 580–608.
(16) Dillan, K.W. *J. Am. Oil Chem. Soc.* 1984, 61, 1278–1284.
(17) Förster, Th.; Issberner, U.; Hensen, H.T. *J. Surf. Deterg.* 2000, 3, 345–352.
(18) Lee, C.H.; Howard, I.M. Sodium Lauryl Sulfate. In *Irritant Dermatitis; Chew, A.; Maibach, H.I, Eds.; Springer-Verlag:* Berlin, 2006; pp 257–267.
(19) Mukherjee, S.; Yang, L; Vincent, C.; Lei, X.; Ottaviani, M.F.; Ananthapadmanabhan, K.P. *Int. J. Cosmet. Sci.* 2015, 37, 371–378.
(20) Nitsch, Ch.; Huttman, G. *SOFW-Journal* 2002, 128, 11–15.
(21) Salgin, U.; Çalimli, A.; Uysal, B.Z. *J. Am. Oil Chem. Soc.* 2004, 81, 293–296.
(22) Sahena, F.; Zaidul, I.; Jinap, S. *J. Food Eng.* 2009, 95, 240–253.
(23) Jia, N.; Kong, B.; Liu, Q.; Diao, X.; Xia, X. *Meat Sci.* 2012, 91, 533–539.
(24) Sovová, H.; Zarevucka, M.; Vacek, M.; Stránský, K. *J. Supercrit. Fluid.* 2001, 20, 15–28.
(25) Yang, B.; Ahotupa, M.; Määttä, P.; Kallio, H. *Food Res. Int.* 2011, 44, 2009–2017.
(26) Kraujalis, P.; Baranauskienė, R.; Venskutonis, P.R. *J. Supercrit. Fluid.* 2015, 104, 234–242.
(27) Fischer, H.; Scheuermann, F.; Hase, C.; Krause, H. Mild to the Skin Anionic Tensides of Basic Protein Aminolysates Preparations Containing Them, and Their Use. US Patent 4,338,214, July 6, 1982.
(28) Imokawa, G.; Sumura, K.; Katsumi, M. *J. Am. Oil Chem. Soc.* 1975, 52, 484–489.
(29) Tavss, E.A.; Eigen, E.; Kligman, A.M. *J. Soc. Cosmet. Chem.* 1988, 39, 267–272.
(30) Hall-Manning, T.J.; Holland, G.H.; Rennie, G.; Revell, P.; Hines, J.; Barratt, M.D.; Baskette, D. *Food Chem. Toxicol.* 1998, 36, 233–238.
(31) Jackson, C.T.; Paye, M.; Maibach, H. Mechanism of Skin Irritation by Surfactants and Anti-irritants for Surfactants Base Products. In *Handbook of Cosmetic Science and Technology Fourth Edition;* Barel, A., Paye, M., Maibach, H., Eds.; CRC Press Taylor & Francis Group; Boca Raton, FL, 2014; pp 353–365.
(32) Moore, P.N.; Puvvada, S.; Blankschtein, D. *J. Cosmet. Sci.* 2003, 54, 29–49.
(33) Dominguez, J.G.; Balaguer, F.; Parra, J.L.; Pelejero, C.M. *Int. J. Cosmet. Sci.* 1981, 3, 57–68.
(34) Phan, T.T.; Attaphong, C.; Sabatini, D.A. *J. Am. Oil Chem. Soc.* 2011, 88, 1223–1228.