Study of mixtures of n-dodecyl-β-D-maltoside with anionic, cationic, and nonionic surfactant in aqueous solutions using surface tension and fluorescence techniques

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Received 18 July 2003; accepted 9 June 2004
Available online 21 July 2004

Abstract

Surfactants of practical interest are invariably mixtures of different types. In this study, mixtures of sugar-based n-dodecyl-β-D-maltoside with cationic dodecyltrimethylammonium bromide, anionic sodium dodecylsulfate, and nonionic pentanoylhexylglycerol monododecyl ether in solution, with and without supporting electrolyte, have been studied using surface tension and fluorescence spectroscopic techniques. Interaction parameters and mole fractions of components in mixed micelles were calculated using regular solution theory. The magnitude of interactions between n-dodecyl-β-D-maltoside and other surfactants followed the order anionic/nonionic > cationic/nonionic > nonionic/nonionic mixtures. Since all surfactants have the same hydrophobic groups, strengths of interactions are attributed to the structures of hydrophilic heads. Electrolyte reduced synergism between n-dodecyl-β-D-maltoside and ionic surfactant due to charge neutralization. Industrial sugar-based surfactant, dodecyl polyglycoside, yielded results similar to that with dodecyl maltoside, implying that tested commercial alkyl polyglycosides are similar to the pure laboratory samples in synergistic interactions with other surfactants. Fluorescence study not only supported the cac results using tensiometry, but showed that interfaces of all the above mixed micelle/solution interfaces are mildly hydrophobic. Based on these results, an attempt is made to discover the nature of interactions to be a combination of intermolecular potential energies and free energy due to packing of surfactant molecules in micelles.

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1. Introduction

Alkyl polyglycosides have attracted considerable attention recently [1–7] due to their environmental compatibility [8,9] and outstanding physical properties such as low surface tension [10] and good electrolyte tolerance [11]. They have been successfully utilized for dermecy, cosmetic, agicultural, and enhanced oil recovery applications [9,10]. However, polydispersity of alkyl polyglycosides has complicated understanding of the relationship between their structures and performance. n-Dodecyl-β-D-maltoside was used as a model substance to represent alkyl polyglycosides in this study.

The micell size, shape, and aggregation number of dodecyl maltoside have been determined in the past by SANS [12–14] technique. Other properties such as aggregation [15], adsorption [16], and phase behavior [17–19] have also been under investigation. Industrial surfactant systems are usually mixtures for economical as well as synergistic reasons. To maximize the beneficial synergistic effects, it is useful to understand interactions among surfactants in mixtures. Holland and Rosingshine [20,21] have developed the regular solution theory (RST) for binary mixtures in solution with basic assumption that the entropy of mixing is zero and only enthalpy change contributes to nonidality. Interaction parameter β was introduced empirically to measure deviation of molecular interactions from ideality [22]. The regular solution theory approach was also extended to monitor the interactions in mixed monolayers at air/water solution interface [23,24].

Research [25–30] on surfactant mixtures has been conducted in the past to study dodecyl maltoside interaction with nonionic [25,27], anionic [28–30], cationic [26], and
zwitterionic surfactants [28,29]. The objective of this work
is to measure interactions of mixtures of sodium dodecylsul-
late, n-dodecyl trimethylammonium bromide and n-dodecyl
pentaneethylenoxyl with dodecyl maltoside with all of them hav-
ing a 12-carbon chain but with different head groups. Do-
decyl polyglycoside was selected for comparing the perform-
ance of dodecyl maltoside with industrial products. Thus
all changes in the interaction are due to the differences in
head groups. Fluorescence technique was used along with
surface tension measurements to probe the polarity of the
microenvironment of micellar/solvent interface.

2. Materials and methods

2.1. Surfactants

Nonionic n-dodecyl-β-D-maltoside of >95% purity from
CabiBiochem and dodecyl polyglycoside with 1.8 polymer-
ization from Henkel Corp., nonionic ethoxylated surfac-
tant pentaristearoylmonoethanolamine ether of >99% pu-
rity from Nikko Chemicals, anionic sodium dodecylsulfate
of >99% purity from Fluka Chemicals and cationic dode-
cyltrimethylammonium bromide of >99% purity from TCI
Chemicals were used as received.

2.2. Other chemicals

A.C.S. certified NaCl from Fisher Scientific Co. was used
as received. Water used in all the experiments was triple
distilled, with a specific conductivity of less than 1.5 μS/cm
and tested for the absence of organics using surface tension
measurements. Fluorescence probe, pyrene, was obtained
from Aldrich Chemicals and used as received.

2.3. Surface tension

The surface tension of nonionic and anionic surfactants
and their mixtures was measured at 25 ± 1 °C with the Wil-
helmy plate technique using a sandblasted platinum plate as
the sensor. For each measurement, the sensor was in con-
tact with surfactant solution for 30 min to allow equilibra-
tion. For cationic surfactant and its mixtures, adsorption of
the cationic surfactant on platinum plate resulted in nonzero
contact angle between plate and air/solution interface. In
this case, surface tension was measured by drop volume
method.

2.4. Fluorescence spectroscopy

A Photon Technology International PTL-LS-100 was used for
fluorescence experiments. Surfactant solutions were pre-
pared using pyrene saturated triple distilled water. The sam-

cles were excited at 335 nm and emission between 565 and
500 nm was recorded. In fluorescence spectroscopy, ratio α'
relative intensities of I₁ (373 nm) and I₂ (383 nm) peaks
(I₁/I₂) on a pyrene emission spectrum showed the greatest
solvent dependency. Polarity a surfactant micelle/water in-
terface [31] was estimated by calculating the polarity para-

ter I₁/I₂.

2.5. Molecular modeling

Molecular structures and optimized geometry were con-
structed using Cache software from Fujitsu.

3. Results and discussions

All surfactants in this study had dodecyl chain as the
hydrophobic tail. Any deviation from ideality could be
attributed to the differences between hydrophobic head groups.

3.1. Sugar-based surfactant/anionic surfactant mixtures

Interaction parameter β is a dimensionless parameter. RT × β (R is the gas constant and T is the absolute tempera-
ture) is the difference in interaction energies between mixed
and unimixed systems. Magnitude of β is a measure of the
deviation of mixtures from single components. A negative β
means synergism, namely, attractive interaction between sur-
factant molecules in mixed micelles than monomers in the
bulk solution. A positive β indicates antagonism or demix-
ing.

To calculate the interaction parameter, one has to solve
surfactant micellar mole fraction first by iterative solution
of following equation [26]:

\[
X_1 \ln \frac{a_{12}}{a_1} \left[\frac{X_1}{X_1 + X_2} \right] = 1, \tag{1}
\]

where \(X_1\) is the mole fraction of surfactant 1 in mixed
micelles, \(a_1\) is the mole fraction of surfactant 1 in total
concentration, \(c_1\) and \(c_2\) are cmcs for surfactant 1 and
2, and their mixture.

By introducing \(X_2\), the interaction parameter \(\beta\) can be
obtained from equation

\[
\ln \frac{a_{12}}{a_1} \left[\frac{X_1}{X_1 + X_2} \right] = \frac{X_1}{1 - X_1}, \tag{2}
\]

Interactions of n-dodecyl-β-D-maltoside with a typical an-
ionic surfactant, sodium dodecylsulfate, were studied first.
Surface tension data obtained for n-dodecyl-β-D-maltoside,
sodium dodecylsulfate, and 3:1, 1:1, and 1:3 n-dodecyl-β-
D-maltoside/sodium dodecylsulfate mixtures at pH 6.5 and
25 °C are shown in Fig. 1 as a function of total concentration.
Relevant data such as critical micelle concentrations, mole
fractions of n-dodecyl-β-D-maltoside in mixed micelles, and
interaction parameters of mixtures are given in Table 1. Mole
fractions and interaction parameters were calculated using
regular solution theory. Interaction parameter at mixing ratio
of 0.25 in the literature [28] agrees well with the results ob-
tained in this work. However, interaction parameters at other
mixing ratios (0.5 and 0.75) differ significantly. pH and sample purity may cause such differences. In this paper, pH is maintained at 6.5 while the pH value is not specified in the literature. cmes for single surfactants obtained in this study are higher than those in the literature, suggesting that the sample used here in this work is possibly pure. Hence cmes for mixtures are different, yielding different interaction parameters. It can be seen that dodecyl maltoside plays a predominant role in mixed micellization at various mixing ratios. In surfactant mixtures, the component with lower cmc usually is present in micelles and at air-water interface at a higher percentage because of its higher surface activity. These results are in accord with the fact that n-dodecyl β-D-maltoside is much more surface active than sodium dodecyl sulfate.

Interaction parameter β is between −4.0 and −3.25 for this system, indicating moderate interaction between n-dodecyl β-D-maltoside and sodium dodecyl sulfate. This β value is typical of nonionic-ionic mixed surfactant systems [28-30]. However, it should be noted that the interaction parameter decreases with increase in percentage of n-dodecyl β-D-maltoside. The mixing of an ionic surfactant with the nonionic one can cause a decrease in the surface charge density of the micelles, so that mixed micelles of ionic and nonionic surfactants are more stable than the micelles containing only the ionic surfactant. Higher the mixing ratio with respect to n-dodecyl β-D-maltoside, less is the surface charge density and hence the interaction is stronger. Both the hydrophobic interactions between the hydrocarbon chains and the ion-dipole interactions of the headgroups contribute to the inter-molecular interactions and thus the interaction is stronger. The ion-dipole interactions of head groups are illustrated in Fig. 2. For simplification purposes, the hydrogen atoms on the hydrocarbon chain are not shown. Three oxygen atoms (except the one connecting with hydrocarbon chain) in the sulfate group of sodium dodecyl sulfate can be expected to interact with the hydrogen atoms in the hydroxyl groups of n-dodecyl β-D-maltoside. Moreover, different surfactant headgroups at the micellar surface can reduce the steric repulsion by adjusting their conformations. Both partial charge neutralization and reduction of steric repulsion favor mixed micellization.

3.2. Sugar-based surfactants/ionic surfactant mixtures

Interactions of sugar-based n-dodecyl β-D-maltoside with the cationic surfactant, dodecyltrimethylammonium bromide, were studied next under different mixing conditions. The surface tension results are exhibited in Fig. 3 as a function of the total concentration. Relevant data for these mixtures are listed in Table 2.

It can be seen from Fig. 3 and Table 2 that a small amount of n-dodecyl β-D-maltoside does affect the surface tension of the mixture to a significant extent. Mole fraction of n-dodecyl β-D-maltoside in micelle is much higher than that in the bulk solution, suggesting that n-dodecyl β-D-maltoside is the dominant component in the micellar phase again due to its higher surface activity in comparison to that of dodecyltrimethylammonium bromide.

Again, the interaction parameter decreases from −1.54 to −0.63 with the increase in percentage of n-dodecyl β-D-maltoside, indicating weak interactions between n-dodecyl β-D-maltoside and dodecyltrimethylammonium bromide.
The charge density of micelles is diluted with the addition of n-dodecyl-β-D-maltoside, resulting in stable micelles. Interestingly, this interaction, however, was less than that between n-dodecyl-β-D-maltoside and sodium dodecyl sulfate. The weaker interaction in cationic/nonionic systems is attributed to the fact that nitrogen atom in the hydrophilic group of dodecyltrimethylammonium bromide is screened by three methyl groups that hinder formation of im-dipole interaction [33]. The small residual charge of a dodecyltrimethylammonium bromide micelle (0.23–0.36 [34–36]) supports this suggestion.

3.3. Sugar-based surfactants/nonionic ethoxylated surfactant mixtures

Even though sugar-based surfactants are nonionic, their interfacial properties are found to be quite different from that of the commonly used nonionic ethoxylated surfactants. For example, the sugar-based surfactant adsorbs on alumina but very little on silica [37] while the behavior of nonionic ethoxylated surfactants is in opposition [38,39].

Results obtained for surface tension of n-dodecyl-β-D-maltoside mixtures with pentaethylene glycol monododecyl ether are given in Fig. 4 and Table 3. Values obtained for cmc's are in agreement with those reported in the literature [11,13,21]. In these systems, pentaethylene glycol monododecyl ether is more surface active than sugar-based surfactants, even though both have the same hydrocarbon chain. This suggests a higher hydrophilicity of two sugar groups than that of five ethoxylated groups. For nonionic surfactants, clouding phenomenon could be used to judge the hydrophilic properties. Dissolution of these surfactants in water relies on formation of hydrophobic bonds between hydrophilic head and water molecules. n-Dodecyl-β-D-maltoside does not exhibit clouding up to 45% concentration [40] while pentadecylglyceryl monododecyl ether solutions clouds at much lower concentrations (0.02%) with a phase transition temperature of around 30°C [41]. Since hydrophilic materials have high surface tension [42], the surface tension values above cmc are used here to test the above considerations. Experimental results show n-dodecyl-β-D-maltoside to have a higher surface tension of 35.5 mN/m than 30.0 mN/m for pentadecylglyceryl monododecyl ether.

Rosen et al. [43] have investigated interaction between n-dodecyl-β-D-maltoside and hexadecyl hexaethoxyxethanol by means of surface tension measurements and determined interaction parameter to be ~0.05. Similar value was determined to be 0.05 for mixtures of n-dodecyl-β-D-maltoside and pentadecylglyceryl monododecyl ether, indicating almost ideal mixing in solutions. These low values of interaction parameters are expected since both surfactants are
Fig. 4. Surface tension vs. concentration of n-dodecyl-β-D-maltoside and pentadecylmethylglycol monododecyl ether mixed systems without salt, pH 6.5, temperature 25°C. In above figure, DM and C12EO5 stand for n-dodecyl-β-D-maltoside and pentadecylmethylglycol monododecyl ether, respectively.

Table 3
Results of surface tension data analysis for n-dodecyl-β-D-maltoside (DM)/pentadecylmethylglycol monododecyl ether (C12EO5) mixtures without salt at 25°C

<table>
<thead>
<tr>
<th>Concentration, M</th>
<th>0.00001</th>
<th>0.0001</th>
<th>0.001</th>
<th>0.01</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM: C12EO5</td>
<td>0</td>
<td>0.0051</td>
<td>0.00013</td>
<td>0.000006</td>
</tr>
<tr>
<td>Mole fraction of mixture</td>
<td>0.52</td>
<td>0.26</td>
<td>0.11</td>
<td></td>
</tr>
<tr>
<td>Interaction parameter β</td>
<td>0.11</td>
<td>0.03</td>
<td>0.01</td>
<td></td>
</tr>
</tbody>
</table>

Table 4
Summary of results for sugar-based surfactants in mixtures. DM, SDS, APG, DTAB and C12EO5 stand for n-dodecyl-β-D-maltoside, sodium dodecylsulfate, dodecyltrimethylammonium bromide, and pentadecylmethylglycol monododecyl ether, respectively.

<table>
<thead>
<tr>
<th>Mixtures</th>
<th>Nonionic/nonionic</th>
<th>Nonionic/nonionic</th>
<th>Nonionic/nonionic</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM: SDS</td>
<td>APG: SDS</td>
<td>DM: DTAB</td>
<td>APG: DTAB</td>
</tr>
<tr>
<td>β (w/o-salt)</td>
<td>-4 to -3.25</td>
<td>-1.54 to -0.43</td>
<td>0.01 to 0.11</td>
</tr>
<tr>
<td>I (w/ail)</td>
<td>-2.89</td>
<td>-3.20</td>
<td>-0.62</td>
</tr>
</tbody>
</table>

Nonionic. Possible driving forces for interaction can hence be considered to be dipole-dipole, dipoleиндuced dipole and London dispersion type. These forces are much weaker than the ion-dipole interaction for the ionic-nonionic surfactant mixtures discussed above.

3.4. Effect of salt

To study the effect of salt on surfactant interactions in mixed systems, surface tension of n-dodecyl-β-D-maltoside sulfate and n-dodecyl-β-D-maltoside/dodecyltrimethylammonium bromide mixtures of 1:1 mixing ratio was measured in 0.03 M NaCl solutions and results for interactions are given in Table 4. It is clear that the presence of salt does reduce the synergy between the surfactants. For n-dodecyl-β-D-maltoside/sodium dodecyl sulfate mixtures, interaction parameter is reduced from -3.77 to -2.89, and for n-dodecyl-β-D-maltoside/dodecyltrimethylammonium bromide system from -1.54 to -0.62. The decrease is mainly due to charge neutralization by sodium counterions for n-dodecyl-β-D-maltoside/sodium dodecyl sulfate and chloride ions for n-dodecyl-β-D-maltoside/dodecyltrimethylammonium bromide mixtures. This also verifies the importance of electrostatic interaction in synergism.

3.5. Alkyl polyglycoside mixtures with other surfactants

To correlate behavior of laboratory dodecyl maltoside sample with that of industrial samples, an alkyl polyglucoside sample, dodecyl polyglycoside mixed with sodium dodecyl sulfate, dodecyltrimethylammonium bromide and pentadecylmethylglycol monododecyl ether was studied. Results obtained for these mixtures are given in Table 4. Again, the sugar-based surfactant is the dominant one in alkyl
polyglucoside/sodium dodecyl sulfate and alkyl polygluco-
side/dodecyltrimethylammonium bromide systems. Interac-
tion parameters for dodecyl polyglycolacrose/sodium dodecyl
sulfate and alkyl polyglucoside/dodecyltrimethylammonium
bromide systems are $-3.20$ and $-0.41$, respectively, sug-
gestening moderate synergistic interaction between dodecyl
polyglucoside and sodium dodecyl sulfate, and weak inter-
action between dodecyl polyglycolacrose and dodecyltrimethyl-
ammonium bromide. In the case of dodecyl polyglycolacrose/
pentanethyleneglycol monododecyl ether mixtures, the in-
teraction parameter is $-0.11$, close to that for ideal mix-
ing. Similarities in interactions between n-dodecyl-$\beta$-O-
maltoside and dodecyl polyglycolacrose with other surfactants
imply that commercial polyglycolacroses are similar to the
pure laboratory samples in synergistic interfacial interac-
tions with other surfactants.

Surface tension of dodecyl polyglycolacrose above cmc was
lower than that for n-dodecyl-$\beta$-D-maltoside due to the
formation being a mixture of surfactants with one and two
sugar groups. Alkyl glucoside is hence less hydrophilic and
more surface active than the maltoside. Thus, surface ten-
sion of decyl glucoside at cmc is 28.1 mN/m compared
with 36.9 mN/m for decyl maltoside [43]. Dodecyl glucoside
has a low solubility in water. The small negative interac-
tion parameter for industrial sample and pentanethyleneglycol
monododecyl ether supports the fact that mixtures of malt-
oside and polyethylene oxide surfactants have stronger in-
teractions than those of laboratory n-dodecyl-$\beta$-D-maltoside
with ethoxylated surfactants [44].

3.6. Fluorescence spectroscopy

To acquire information on the property of mixed mi-
celles, surfactant mixtures were studied by fluorescence
spectroscopic technique. Pyrene was polarity probe and po-
larity parameter, $I_3/I_1$, was used to estimate the polar-
ity at the micelle/solution interface. The polarity parame-
ter of pyrene is determined as a function of concentration for
the n-dodecyl-$\beta$-D-maltoside/sodium dodecyl sulfate, n-
dodecyl-$\beta$-D-maltoside/dodecyltrimethylammonium brom-
ide and n-dodecyl-$\beta$-D-maltoside/pentanethyleneglycol-
monododecyl ether mixtures, respectively.

At low surfactant concentrations, value of polarity pa-
rarameter corresponded to that for water (0.5–0.6). Polarity parameter increased around cmc as measured by surface ten-
siometry, cmc values, polarity parameters of pyrene at con-
centrations above cmc and mle fraction of dodecyl mal-
toside in mixed micelles are given in Table 5. $I_3/I_1$ ratio for
n-dodecyl-$\beta$-D-maltoside/sodium dodecyl sulfate mix-
tures above cmc is similar to that for sodium dodecylsul-
fate and n-dodecyl-$\beta$-D-maltoside system, suggesting simi-
lar hydrophobicity for micelles of n-dodecyl-$\beta$-D-maltoside,
sodium dodecyl sulfate and their mixtures. The polarity pa-
rarameter number is less than those for hydrocarbons, suggest-
ing that interface, as expected, is a mixture of hydrocarbon chains and small amount of water. The addition of salt in-
creases polarity of the solvent as well as that at interface. For
n-dodecyl-$\beta$-D-maltoside/dodecyltrimethylammonium bro-
mide system, $I_3/I_1$ ratio for n-dodecyl-$\beta$-D-maltoside above
cmc is higher than that for dodecyltrimethylammonium bromide,
suggesting that the interface of n-dodecyl-$\beta$-D-
maltoside micelles is more hydrophobic than that of do-
decyltrimethylammonium bromide micelles, possibly be-
cause of bulk nature of the trimethylammonium head group
causing a less dense packing of hydrocarbon chains. In the
case of mixtures, the predominance of n-dodecyl-$\beta$-
maltoside in mixed micelle increases hydrophobicity for the
micelle. This polarity parameter of n-dodecyl-$\beta$-D-
maltoside/dodecyltrimethylammonium bromide mixed mi-
celle yields a more hydrophobic interface. Polarity param-
eter of n-dodecyl-$\beta$-D-maltoside/dodecyltrimethylammoni-
num bromide mixed micelle is only slightly lower than that
for n-dodecyl-$\beta$-D-maltoside. In the case of n-dodecyl-$\beta$-
D-maltoside/pentanethyleneglycol monododecyl ether sys-
tem, $I_3/I_1$ for both n-dodecyl-$\beta$-D-maltoside and pen-
tanethyleneglycol monododecyl ether are similar at con-
centrations higher than cmc, indicating similar hydropho-
bitics for interface of micelles of both surfactants. Since
pentanethyleneglycol monododecyl ether is predominant in
mixed micelles, polarity parameter of the mixed micelle is
close to that for pentanethyleneglycol monododecyl ether.
Thus in the case of mixtures of sugar-based surfactant with
ionic ones, mixed micelle characteristics could be con-
cluded to be similar to that of nonionic sugar-based surfactant.

4. Nature of interaction

Mixed cmc can also be predicted from phase separation
model by assuming ideal mixing of components, that is, micellar activity coefficients of surfactant components are
equal to unity [45]:

$$
\frac{1}{C_{12}} = \sum a_i \frac{1}{C_i}
$$

(3)
where $\alpha_i$ and $C_i$ are composition and cmc of surfactant component $i$, respectively.

Cmc's of the three surfactant combinations obtained from theoretical calculations for ideal mixing are compared with those from surface tension measurements in Fig. 5. Calculated cmc's for $n$-dodecyl-$\beta$-D-maltoside, sodium dodecylsulfate, $n$-dodecyl-$\beta$-D-maltoside-dodecyltrimethylammonium bromide, $n$-dodecyl-$\beta$-D-maltoside-practanol/glycol monododecyl ether with these calculated by assuming ideal mixing of components.

To understand the magnitude of the interaction parameter of surfactant mixtures, the potential energies for ion: dipole, $\alpha$-dipole--dipole, induced dipole-induced dipole interactions are taken into account. Electrostatic interaction is very strong compared to other interactions. Magnitude of the intermolecular interactions follow an order: electrostatic interaction $>$ ion: dipole $>$ dipole--dipole $>$ ion-induced dipole $>$ dipole-induced dipole $>$ London dispersion [46]. Ion–dipole interaction is responsible for properties of sodium dodecylsulfate and dodecyltrimethylammonium bromide mixtures with n-dodecyl-$\beta$-D-maltoside. Dipole--dipole, dipole-induced dipole, and London dispersion interaction are the main driving forces for pentanethyleneglycol monododecyl ether and n-dodecyl-$\beta$-D-maltoside mixtures. Since bulky loose structure of the hydrophobic head of dodecyltrimethylammonium bromide will prevent direct contact with hydrophilic groups in $n$-dodecyl-$\beta$-D-maltoside, this interaction can be expected to be less than that for sodium dodecylsulfate and n-dodecyl-$\beta$-D-maltoside.

Interaction parameter of $n$-dodecyl-$\beta$-D-maltoside and pentanethyleneglycol monododecyl ether is around zero as shown in Fig. 6. The data for the mixtures of $n$-dodecyl-$\beta$-D-maltoside with sodium dodecylsulfate and with dodecyltrimethylammonium bromide [40] are also given in this figure. There are decreasing trends in cationic–nonionic and anionic–nonionic surfactant mixtures. We have proposed these tendencies to be due to the asymmetry of excess free energies with respect to the micellar compositions [47]. To simplify treatment of regular solution theory, only contribution of electrostatic interaction is considered for ionic/nonionic surfactant mixtures. However, ionic interactions between surfactant hydrophilic heads and packing restrictions of the hydrophobic groups in the core can also be expected to contribute in this case. Shah and coworkers have found that maximum performance of surfactant mixtures occurs at a certain mixing ratio in accord with packing of molecules at air/water interface and in micelles [48–50].

8. Summary

Surface tensiometry and fluorescence spectroscopy have been used to study mixtures of sugar-based $n$-dodecyl-$\beta$-D-maltoside and $n$-dodecyl polyglycoside with cationic, anionic, and nonionic surfactants with and without supporting electrolyte. Interaction parameters estimated from surface tension data suggest interactions between $n$-dodecyl-$\beta$-D-maltoside with other surfactants to follow an order anionic/nonionic > cationic/nonionic > nonionic/nonionic. Moderate synergy between stage-based surfactants with cationic and anionic surfactants is considered to be due to ion–dipole interactions. On the other hand, behavior of mixtures of nonionic surfactants is close to that for ideal mixing, synergistic effects being mainly due to entropic contributions of surfactant headgroups [51].

Presence of salt is found to reduce synergy between surfactants mainly due to charge neutralization by counter ions. Interaction parameter decreases with mole fraction of $n$-dodecyl-$\beta$-D-maltoside in dodecyl maltoside/sodium dodecylsulfate and dodecyl maltoside/dodecyltrimethylammonium bromide systems.

Polarity parameter, as determined by fluorescence, shows interfacial regional of all studied micelles/solution to be mildly
hydrophobic. Industrial dodecyl polyglycoside dodecyl poly-

References

closide yielded results similar to those for dodecyl malto-

Acknowledgments

We express our gratitude to Dr. Dinesh O. Shah at Uni-

verse of Florida for helpful discussions. Support of this

work by the Department of Energy (DE-AC26-90BC15112,

DE-AC26-90BC15112), National Science Foundation

9804618, and industrial sponsors of the Industry/University

Cooperative Research Center (I/UCRC) for Advanced Stud-

ey on Novel Surfactants at Columbia University is also

gratefully acknowledged.

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