

ANALYSIS OF EFFICIENCY OF SURFACTANTS IN MULTIFUNCTIONAL TEXTILE COMPOSITIONS

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Abstract:

Washing mechanism in an aqueous and non-aqueous mediums was analysed including all stages of removal of soils from textile materials. It was shown that remnant of surfactants on fabric effect on its properties and can modify surface of fibres. Physical and chemical properties of modern surfactant and textile chemicals have been studied. Estimation and choice of effective surfactants for washing process was based on their solubilizing, emulsifying and dispersing abilities. Optimal composition of detergents was determined by mathematical methods with use of regression analysis. Research of adsorption of nonionic surfactants on synthetic fabric showed that adsorption isotherms of OS-20 have S-shape and its molecules are held on the polyamide and polyester fibers by the Van der Waals forces. Application of elaborated composition for dry cleaning improves performance of materials and facilitates subsequent care about clothes.

Keywords:

Washing ability, surfactant, detergent, adsorption, modification of fabric surface

Introduction

The main process of the soil removal from the textile materials is washing in aqueous solutions of detergents in the washing machines or in the organic solvent of dry-cleaning. Detergency is characterized to a greater or lesser degree for washing medium (water, organic solvents) and the washing agents (surfactants, detergents) in water and solvents. Meanwhile we must distinguish between physical and chemical effects on textiles during washing, which are associated with the detergency of surfactant and washing medium, and mechanical influences on materials during processing in the drum of a washing or dry-cleaning machines.

Theory of washing process

The theory of detergency of surfactants in aqueous solutions has been elaborated and fully grounded so far [2,3,8 etc], but the concept of the mechanism of detergency in a non-aqueous mediums is not enough developed, especially, in respect of role of water and other active additions in dry-cleaning [1,4,9].

Summarizing the information in literature, it is possible to distinguish the following stages of the washing mechanism, which takes place in an aqueous and non-aqueous mediums at the cleaning of textile materials from contaminations:

1. wetting of textile material and its polluted surface by washing solution;
2. adsorption of components of washing solution on the surface of material and contaminations;
3. displacement, separation and removal of particles of contaminations out of material as a result of dissolution, solubilization, emulsification, suspending action of washing solution with simultaneous formation of adsorption layers of surfactants on the cleaned surface and contaminations;
4. stabilizing and suspending of contaminations in the washing solution for prevention of their redeposition on the surface of material (protective action);
5. removal of washing liquid together with contaminations from the area of contact with material by use spinning or drain as a rule;
6. removal of remnants of contaminations and detergents from materials by a rinse.

Stages 5 and 6 are not included directly in a washing process. But, because of necessity to finally get cleaned textile material, these stages must be considered in the process of removal of contaminations. More over, there is relationship between stability of soil dispersion in a washing solution and the operation of their removal from washing drum. Also remnants of surfactants on fabric effect on its properties and can modify surface of fibres.

One of perspective directions of improvement of washing process is the development and applications of new washing compositions, which have multifunctional action on textile properties including anti-static, dirt-resistant, hydrophilic finishing.

Experimental research

Methodologies

Colloid and chemical properties of different anionic (Sulfonol NP-3), nonionic (OS-20) and other surfactants have been researched. Also complex textile chemicals have been studied which are used in textile industry (Fibro-tex 4, 25, 40). These chemicals consist of ethoxylated nonylphenol with 9, 10 or 12 mol ethoxylation level, methyl or ethyl esters of fatty acids of oil and other additions. These substances are manufactured in Ukraine.

Nonionic surfactant OS-20 is ethoxylated octadecyl alcohol, its formula and one of the possible configuration in the aqueous solution is shown in Fig. 1.

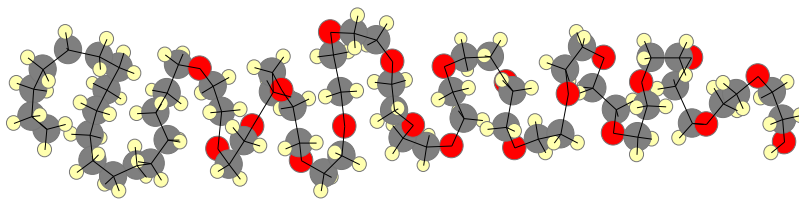


Figure 1. Geometric form of molecules OS-20 in the aqueous solution

Colloid and chemical properties of surfactants have been determined by standard methods. Critical micelle concentration (CMC) has been estimated by different methods which gave good convergence of results. Thus, second CMC (1 kg/m^3) has been obtained that is typical of mixed and complex textile chemicals.

Basic physical and chemical characteristics of surfactants have been determined by the isotherms of surface tension of their aqueous solutions.

The cleaning power of the investigated solutions for the washing of the woolen and polyester fabrics from mixed soil on the basis of oil and soot has been estimated.

Standard methods were used for determination of physical and mechanical properties of woolen and polyester fabrics.

Results and discussion

Physical and chemical properties of surfactants

Surfactants have a basic role in strengthening of detergency of organic solvents in dry-cleaning process. Organic solvents moisten fibres practically instantly in contrast to the aqueous medium, where surfactants are used for the decrease of surface tension and improvement of wetting of dirty surface. Therefore we need to define clearly, what functions must be executed by surfactant in a non-aqueous medium.

Development of optimal conditions of the use of surfactants at their minimum quantity is possible only on the basis of research and complex analysis of their physical and chemical, colloid and technological properties. It is necessary to predict what role will be executed by surfactants in the washing process: an effective wetting agent, solubilizer, emulsifier, dispersant, antistatic, protective agent and which of these properties will determine the choice of surfactant as a detergent.

Up to now there has been collected large experimental material about research of specific properties of surfactants and intercommunication between them, but there is a considerable gap between practical and chemical properties of surfactants.

In our opinion, a detergency can be estimated only by the practical indexes of quality of washing by the amount of removed contaminations from materials and their cleanness which usually is estimated by a gravimetric method or the whiteness of materials. On the other hand, there is connection between detergency and the display of specific colloid properties of surfactants: solubilization, emulsification and suspending capabilities. Therefore it is necessary to determine chemical, colloid and functional properties of surfactants for following choice of the most effective detergents and textile chemicals [6].

To determine the applicability of the mentioned above surfactants in the technological treatment of the textile materials the basic physical and chemical properties of their aqueous solutions have been studied. The results are given in Table 1: CMC – critical micelle concentration at 20°C [kg/m^3]; σ – surface tension of the aqueous solution of the surfactant at CMC and 20°C [mN/m]; $\Delta\cos\theta$ – change of cosine of equilibrium contact angle on the paraffin surface in the presence of surfactants; Γ_m – interfacial adsorption of the surfactant on the interphase surface solution – air [mmol/m^2]; a_m – area per molecule in a filled monolayer [m^2]; W_w – work of surface wetting [J/m^2]; W_a – work of adhesion to solid surface [J/m^2]; W.N. – water number [ml] and E.N. – ethanol number [ml]; S_d – solubilization of the dye Sudan III [g/m^3]; S_b – solubilization of benzene [kg/m^3]; H – height of foam [cm]; S – stability of foam [%].

According to the theory of Petr Rebinder [8] detergency of surfactants depends on two main factors: their surface activity and surface strength of their films in an aqueous medium, which in turn depend on degree of dispersion of detergents in solution and are described by the curves with a maximum. These two factors are the initiators of the detergency of surfactants mainly in the first two stages of the cleaning process. In our

opinion, the limiting and long-time stage is the third stage of the washing process, i.e. the separation of contaminations from the material. This indicates that the surfactant should have sufficient solubilizing, emulsifying and dispersing abilities. We think that the inclusion of these three properties of surfactants should be a priority in selection of detergents.

Table 1. Physical and chemical properties of surfactants

№	Properties	Sulfonol NP-3	OS-20	Fibro-tex 4	Fibro-tex 25	Fibro-tex 40
1	CMC	0.3	0.1	0.4	0.35	0.2
2	σ	47.7	54.56	24.4	27.5	27.2
3	$\Delta\sigma/\text{CMC}$	83.5	181.9	120.88	129.29	227.75
4	Γ_m	0.0295	0.15	0.00219	0.00862	0.00698
5	a_m	$5.63 \cdot 10^{-20}$	$1.11 \cdot 10^{-19}$	$7.59 \cdot 10^{-19}$	$1.93 \cdot 10^{-20}$	$2.38 \cdot 10^{-19}$
6	$\Delta\cos\theta$	0.706	0.498	0.786	0.726	0.805
7	$\Delta\cos\theta/\Delta\sigma$	0.0327	0.0274	0.0162	0.016	0.0177
8	$\Delta\cos\theta/\text{CMC}$	2.353	4.981	1.964	2.073	4.026
9	W_w	39.07	33.35	21.75	23.06	24.98
10	W_a	86.77	87.91	45.95	50.56	52.18
11	W.N.	26	32.4	17.8	10	11
12	E.N.	21	11	11.2	14.8	16.2
13	S_a	0.504	0.2	0.46	0.577	0.689
14	S_b	2.059	1.236	0.613	2.851	0.532
15	H	13.6	2.87	3.3	2.34	2.37
16	S	97	85	91	93.8	99.2

Determination of optimal composition

According to the stated tasks on the first stage the choice of surfactants has been done and detergency of compositions have been studied on the basis of realization of complete factor experiment 2^3 and plan of Box B_3 . Coefficients of regressions and estimation of their meaningfulness have been calculated by standard methods with the use of programs EXCEL 2003 and MATHCAD 2001.

The search of optimal washing composition was conducted by two methods:

- by graphic optimization on parameters of regression equations and projections drawing of corresponding surface sections of functions at the fixed values of factors;
- by means of intrinsic functions of the determination of a maximum and a minimum in MATHCAD.

So, as a result of optimization we got optimal universal composition which can be applied for cleaning both wool and the mixed fabrics. Optimal composition consists of mixture of anionic and nonionic surfactants and aliphatic alcohols [7].

Properties of textile materials

Adsorption of surfactants on the surface of fibres occurs during treatment of textile materials by solutions of surface-active agents, which results in the change of their properties. Often the adsorption methods are used for modification and functionalization of material's properties by surfactants, which allows to change properties of surface of fibres *in situ* and to influence on processes at the interface.

The spectrophotometric method has been applied to determine the adsorption of the nonionic surfactants on the polyamide and polyester fabrics (Fig. 1). It has been

found out that adsorption isotherms of OS-20 have S3-shape by classification of Giles and his coauthors [5].

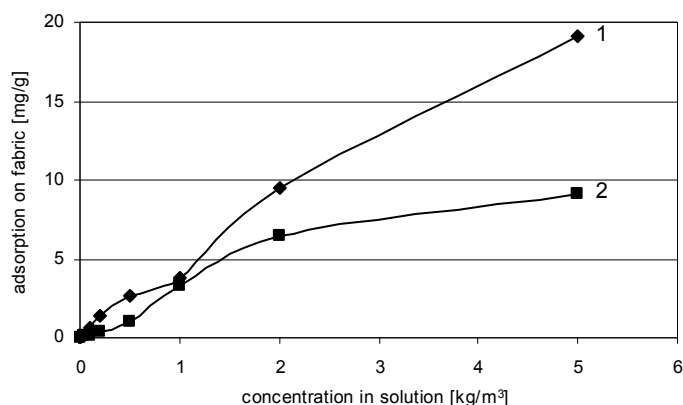


Figure 2. Adsorption isotherms of OS-20 on the polyamide (1) and polyester (2) fabrics

It was found that the adsorption of OS-20 increases sharply at concentration near to CMC. In this case the molecules of nonionic surfactant try to be situated on a surface as chains or clusters. Such location of them is connected with adsorption of solvent, large molecular mass and geometry of molecules of surfactant. Appearance of plateau after CMC (0.2-0.5 kg/m³) can be explained by reorientation of micelles and forming of monolayer and hemimicelles. Adsorption of OS-20 on fibres increases through diffusion mechanism at the further increase of concentration of OS-20 in solution. Molecules of OS-20 are held on the polyamide and polyester fibers by the Van der Waals forces. After treatment of materials in solution with the concentration of surfactant 20 kg/m³ the concentration of the surfactant on the fabrics is as following: polyamide – 65.27 mg/g, polyester – 57.59 mg/g.

The OS-20 adsorbed molecules on the synthetic fibers increase their hygroscopicity by 2–4 times and reduce their surface electrical resistance to 2.1–3.5x10⁹ Ω.

The mechanical properties of woolen and polyester fabric (tensile strength (Ts), elongation (ε), stiffness (St), wrinkle resistance (Wr)) after a single treatment (1 tr.) and fivefold (5 tr.) in one of the elaborated compositions have been determined. The relative changes of these properties (%) in comparison with untreated fabric are presented in Table 2: 1 – treatment in perchlorethylene (PCE), 2 – treatment in the composition (+ increase, - decrease of values).

Table 2. The relative changes of mechanical properties (%) of fabrics

Property	Woolen fabric				Polyester fabric			
	Warp		Weft		Warp		Weft	
	1 tr.	5 tr.	1 tr.	5 tr.	1 tr.	5 tr.	1 tr.	5 tr.
Ts1	-21.2	-25.0	-24.0	-30.6	-6.7	-7.6	-27.8	-31.3
Ts2	-9.8	-10.3	-15.7	-14.2	-1.6	-4.0	-7.3	-10.4
ε1	+15.2	+16.6	+14.7	+13.3	+98.4	+98.4	+21.0	+19.3
ε2	+6.1	+10.6	+5.9	+11.8	+90.3	+94.3	+8.7	+10.5
St1	+20.0	+86.1	+16.7	+57.8	+3.2	+7.0	+15.9	+36.2
St2	+53.1	+108.2	+50.0	+76.7	+24.4	+48.2	+50.7	+64.4
Wr1	-11.1	-11.7	-11.4	-11.7	-3.6	-3.8	-5.3	-7.9
Wr2	-2.2	-3.4	-0.7	-1.6	-0.2	-3.1	-2.9	-5.9

Studies have shown, that a sharp decrease of strength of fabric samples occurs after the first cycle of treatment. Increase of elongation with simultaneous decrease of strength of materials is observed after repeated treatments in the medium of organic solvents. Data analysis shows, that woolen and polyester fabrics stiffness and wrinkle resistance increase with increasing of cycles of treatments. The increasing ability of fabric for recovery of the initial state is better in comparison with untreated sample. Safety of consumer performance of materials after dry-cleaning and reducing of negative influence of cleaning processes are achieved by the application of detergents and a careful selection of components of washing compositions.

Conclusion

In conclusion it should be mentioned that the investigated surfactants can be used in cleaning compositions that are characterized by effective detergency at low concentrations in washing solution. Also adsorption of components of these detergents can modify surface of fibres and it can be possible to regulate antistatic, dirt-resistant, hydrophilic and other properties of the synthetic materials. That is especially important to facilitate the care of clothes during laundering and dry-cleaning. Application of elaborated composition for dr-cleaning improves the performance of materials and facilitates subsequent care about clothes.

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