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Current Trends in Development of Surfactants and Study of Colloidal Chemical Characteristics of their Solutions

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ABSTRACT: The article considers modern approaches to the development and application of surfactants and the analysis of their colloidal-chemical characteristics. Particular attention is paid to non-ionic surfactants based on natural fatty acids, which are environmentally friendly and have low toxicity. The classification of surfactants and the influence of their structure on functional properties, such as micelle formation, Kraft temperature and cloud point, are described. These properties allow surfactants to be optimized for various industrial applications, including textile, petrochemical and agricultural industries.

KEYWORDS: surfactants, colloidal chemical properties, nonionic surfactants, micelle formation, Kraft temperature, environmental safety, emulsions, industrial applications.

I.INTRODUCTION

The creation of new surfactants and the study of their colloidal-chemical characteristics is of primary importance in various industries, such as textile, petrochemical, cosmetic and agricultural. Particular attention in modern chemistry is paid to the synthesis of non-ionic surfactants based on natural fatty acids. These substances have unique physicochemical properties that make them attractive for a wide range of applications. Non-ionic surfactants are characterized by excellent solubility, biodegradability and low toxicity, which meets growing environmental requirements.

II. SIGNIFICANCE OF THE SYSTEM

The article considers modern approaches to the development and application of surfactants and the analysis of their colloidal-chemical characteristics. The study of methodology is explained in section III, section IV covers the experimental results of the study, and section V discusses the future study and conclusion.

III. METHODOLOGY

Surface-active substances (SAS) are a class of chemical compounds that are in demand in the textile, cosmetic, food and petrochemical industries, as well as in agriculture due to their unique surface properties [1, 2]. Their classification is based on the type of hydrophilic head part - anionic, cationic, non-ionic or amphoteric, which determines the chemical and physical properties of each type and their functionality in various processes. Surfactants are adsorbed at the interface of phases (liquid, solid or gaseous), reducing the interfacial tension due to their amphiphilic structure with a polar head and a non-polar tail [1]. An extensive review of the literature on the characteristics and application of surfactants is presented in the reference book [3], and [4] describes their use in chemical methods of enhancing oil recovery. There are four types of surfactants depending on the charge on the hydrophilic head: non-ionic, anionic, cationic and zwitterionic [5]. This is clearly shown in Fig. 1. Surfactants usually have a chain structure due to the hydrophobic tail [6]. According to [7], the tail group often consists of a polymer, hydrocarbon, siloxane or fluorocarbon chain. On the other hand, the head consists of fragments such as sulfates, sulfonates, polyoxyethylene chains, carboxylates, alcohols or quaternary ammonium salts, which forms the amphiphilic nature of the SAS.

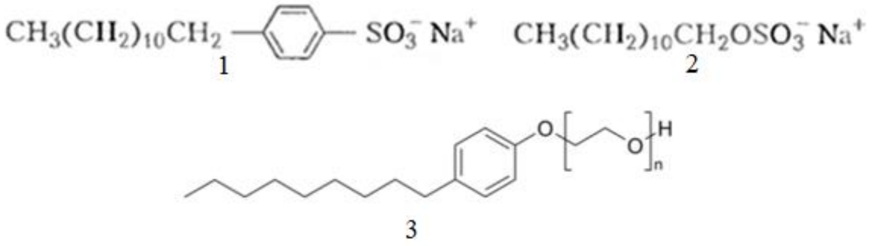

Fig. 1. Structure of surfactant molecules: 1) sodium dodecylbenzenesulfonate 2) sodium dodecyl sulfate; 3) neonol

Solutions of nonionic surfactants (NSAs) do not dissociate into ions, and their surface activity is determined by the presence of polar groups. An example of such substances are neonols, which are oxyethylated derivatives of nonylphenols and have the general formula CnH2n+1O(C2H4O)mH. For example, for neonol AF 9-12, the values of n and m are 9 and 12, respectively. Substances known as amphoteric surfactants contain a hydrophilic radical that can act as a proton acceptor or donor depending on the pH of the solution. These compounds include both alkaline and acidic groups. With a change in pH, amphoteric surfactants can exhibit the properties of both cationic and anionic substances. Studies [8] show that at certain pH values, called the isoelectric point, the molecules of these surfactants are in the form of balanced dipolar ions. Amidobetaines such as RCONH(CH2)3N+(CH2)2COO– are an example of such compounds.

The division of surfactants by solubility is conventionally divided into two groups: colloidal and truly soluble. This division is conditional, since the same surfactant can belong to both groups depending on the temperature, concentration of the solution and the chemical nature of the solvent. The difference between these groups is determined by the value of the hydrophilic-lipophilic balance (HLB), which is a dimensionless numerical coefficient and is calculated as follows.

$$\lambda = (b + Tv)/a \qquad (1)$$

where $(b + Tv)$ denotes the degree of affinity of the non-polar part of the surfactant molecule for the hydrocarbon liquid. Here, b is a dimensionless parameter that depends on the type of surfactant, Ψ is the free energy of interaction per one CH2 group, and v is the number of CH2 groups in the hydrocarbon radical. The parameter a reflects the affinity of the polar group for water [9]. HLB is an important criterion for the classification of surfactants and measures their degree of hydrophilicity or lipophilicity [10]. On a scale from 0 to 20, HLB indicates the tendency of a surfactant to dissolve in water or oil. A value of 0 corresponds to completely lipophilic compounds, while a value of 20 refers to completely hydrophilic substances. For proper selection of surfactants in oil production, it is necessary to use surfactants with a low HLB for low salinity formations and with a high HLB for high salinity formations [11].

Analysis of existing data demonstrates the relationship between the hydrophilic-lipophilic balance (HLB) values, the solubility of surfactants in water and their respective areas of application. Surfactants with an HLB range of 3-6 are insoluble in water and are used as emulsifiers for oil-in-water (O/W) emulsions. Such emulsifiers contribute to the creation of stable emulsions due to the formation of hydrophobic structures around oil particles.

In the HLB range of 7-8, surfactants are dispersed in water, exhibiting wetting properties. They improve the contact of surfaces with water, reducing surface tension. This property allows surfactants from this group to effectively interact with the surface, making it more susceptible to water. Surfactants with HLB 8-12 form solutions that vary from opalescent to transparent and are used as emulsifiers to stabilize direct emulsions, such as oil-in-water emulsions. At HLB 12-15, surfactants are completely soluble in water, forming transparent solutions, which makes them ideal detergents. Such surfactants effectively remove dirt due to their dissolving properties and form stable solutions when mixed with water. At higher HLB values, surfactants also form transparent solutions and are used as solubilizers - substances that increase the solubility in water of compounds that are poorly soluble under normal conditions. Classification by solubility shows that surfactants are conventionally divided into colloidal and truly soluble. This difference determines their functionality in solutions, which is reflected in their application. The Griffin method and the Davis method allow the HLB to be estimated for specific surfactants, enabling efficient selection of substances for emulsifiers, wetting agents, detergents and solubilizers.

IV. EXPERIMENTAL RESULTS

Study of Colloidal Chemical Properties of Surfactant Solutions: Surface Properties and Micelle Formation Micelles are aggregated structures of surfactant molecules in a liquid colloid. Critical micelle concentration (CMC) is the threshold above which micelles form in a solution, changing its physicochemical properties such as surface tension, viscosity, and conductivity. The CMC value depends on the surfactant structure (e.g., hydrophobic chain length), pressure, salinity, ion composition, pH, temperature, and other factors.

There are over 30 methods for determining CMC, including surface tension and dye adsorption. Direct methods detect CMC by abrupt changes in parameters such as viscosity or conductivity, while indirect methods detect changes in test substances through spectrometry and voltammetry. In oil production, interfacial tension (IFT) is often measured to estimate CMC. The Krafft temperature, also known as the critical micelle temperature [12], is important for understanding the critical micelle concentration (CMC). This temperature typically corresponds to the melting point of a hydrated solid surfactant [13]. Below the Krafft temperature, micellization does not occur and the surfactant itself becomes insoluble [14]. When it is reached, the solubility increases sharply, and a further increase in temperature allows micelles to form when the CMC is reached. The Krafft temperature is often determined by measuring the electrical conductivity of a surfactant solution at different temperatures. In this case, the break point on the conductivity versus temperature graph indicates the Krafft temperature [15]. The concept of the Krafft point is associated with the temperature at which the solubility of the surfactant is equal to the CMC [16]. It is determined experimentally by measuring the solubility, where the intersection of the CMC curve and the solubility curve indicates the value of the Krafft point [17]. Cloud point is the temperature at which aqueous solutions of nonionic surfactants, including polyethoxylated ones, begin to become cloudy [18]. Their solubility depends on hydrogen bonds between the hydrophilic groups of the surfactant and water molecules [19]. As the temperature increases, these bonds weaken, dehydrating the polyoxyethylene chains [20], which leads to phase separation of the solution into two layers: one rich in surfactant, and the second, an aqueous phase with a low concentration of surfactant [21].

In [22], it was shown that the cloud point of nonionic surfactants such as alkoxylated glycidyl ether sulfonate (AGES) reduces their efficiency for enhancing oil recovery at high temperature. When the cloud point is reached, AGES solutions separate into two phases, and this temperature is reduced by adding salt (NaCl). Combining AGES with an anionic surfactant, such as internal olefin sulfonate (IOS), solves the problem, since IOS is more soluble in NaCl at elevated temperatures. The ability of a surfactant to reduce surface tension, determined by the surface activity (G), reaches a maximum in truly soluble surfactants, which is estimated by the initial segment of the σ(c) dependence as the concentration tends to zero.

$$G = \frac{-d\sigma}{dc} \tag{2}$$

For colloidal surfactants, surface activity has the form:

$$G = (\sigma_0 - \sigma_{min})/c_{min} \tag{3}$$

The shape of micelles depends on the distribution of angles and the packing of surfactant molecules. Spherical micelles are formed when the size of the hydrophilic head and the length of the hydrophobic tail are balanced. With an increase in the tail length, cylindrical micelles are formed, which can be oriented parallel or randomly in solution. Lamellar micelles arise with a strong imbalance in the sizes of the head and tail, forming two-dimensional structures [2]. In hydrocarbons, micelles are formed at a low concentration of CMC due to the lower polarity of the medium compared to water, and contain fewer molecules. Reverse micelles can retain water in the polar cores, ensuring the dissolution and transport of hydrophilic substances in the non-polar phase [23]. This makes them useful for extraction, transport of hydrophilic components, as well as the creation of nanoreactors and drug delivery systems. With an increase in the concentration of surfactants in hydrocarbon solvents, a transition from spherical micelles to rod-shaped and then to lamellar structures is observed. These changes in micellar morphology are accompanied by changes in the rheology of the solution, which can lead to the formation of liquid crystalline phases with new optical, mechanical and transport properties [24].

From theory to practice: the cleaning action of surfactants

The cleaning ability of surfactants is based on their ability to reduce surface tension, interact with surfaces and emulsify contaminants. Due to their amphiphilic structure, they have hydrophilic and lipophilic properties, which allows them to effectively remove contaminants of various natures. The principles of the cleaning action of surfactants, outlined by P. Rehbinder in 1935, remain relevant [25]. In research, the cleaning action is often studied using the example of washing fabrics, where contaminants include fats, oil products and dust. From a physicochemical point of view, the cleaning process includes adsorption displacement, wetting, emulsification and solubilization [26]. Surfactants penetrate into microcracks and adhesion zones, drawing contaminants into the dispersion medium, which is accompanied by particle grinding, hydrophilization and stabilization in solution, preventing re-deposition on the surface [26]. Washing processes are enhanced by mechanical action, which can provide up to 60-80% of the effect [27]. To increase efficiency, synthetic and natural detergents with a surfactant concentration of 10-15 g/l are being developed [26]. Studies also evaluate the ability of surfactants to reduce the interfacial tension of water at the boundary with oil, reduce wetting angles and solubilize oil [28-29], as well as their use in formation flooding methods combined with gas and biological methods to enhance oil recovery [30-31]. Experimental data show that water can diffuse onto the surface of glass or silicon dioxide, forming a gel layer [32]. Other studies [33-34] suggest that water from this layer is able to penetrate the oil-water interface, especially near the contact line. Observations [35] confirm the formation of a water film between the oil and the solid surface, allowing even a weak flow to separate an oil droplet from the substrate. In the study [36], cleaning is described as a multifactorial process that depends on the composition of the contaminants, surface characteristics, the nature and concentration of the surfactant, temperature and the intensity of the mechanical action. The cleaning process includes dissociation of micelles, adsorption of anions and the formation of new micelles containing contaminants. Fats are removed both by displacement and spontaneous emulsification, and the efficiency depends on the ability of the surfactant not only to remove contaminants, but also to retain them in solution, which requires high suspending capacity through adsorption at the particle-solution interface.

V. CONCLUSION AND FUTURE WORK

In conclusion, research in the field of surfactant development and analysis of their colloidal chemical characteristics confirms their importance for a wide range of industries, including textiles, petrochemicals, cosmetics and agriculture. Particular attention is paid to the creation of non-ionic surfactants based on natural fatty acids with high environmental safety and low toxicity, which is especially important in the context of tightening environmental standards. Classification and analysis of surfactant behavior in solutions help to better understand the influence of the structure of molecules on their physicochemical properties, allowing them to be optimized for the creation of stable emulsions, increased oil recovery and improved detergent properties. Progress in the study of micelle formation, Kraft temperature and cloud point allows for more accurate prediction of surfactant behavior, expanding their areas of application and increasing efficiency. Modern surfactants are becoming more specialized and environmentally friendly, opening up opportunities for sustainable solutions in industry.

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