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OBTAINING POLYMER-BITUMEN COMPOSITES BASED ON THE MODIFICATION OF CATIONIC SURFACTANTS AND STUDYING THEIR PHYSICAL-MECHANICAL PROPERTIES

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Abstract

Cationic surfactants were synthesized for the production of polymer-bitumen emulsions, and the effects of temperature, reaction duration, and catalyst concentrations on their yield were studied. Based on the modification of the synthesized surfactants, the composition of polymer-bitumen emulsions and the impact of concentration variations on the physical-mechanical properties of the emulsions were determined.

Keywords: *Polymer-bitumen emulsion, cationic surfactant, stearic acid, N,N-dimethylethylenediamine, benzyl stearamide, viscosity*

Indroduction

Cationic surfactants (CSFM) used in bitumen emulsions primarily serve to improve the mixing properties of bitumen with water and enhance adhesion to the stone layer. These surfactants possess the necessary surface-active properties to emulsify bitumen in water, ensuring the stability of the emulsion. Additionally, cationic surfactants play a crucial role in increasing the stability of bitumen, improving dispersion, and facilitating better mixing of bitumen with water (Miljković, M. and Radenberg, M., 2014).

The primary goal of using bitumen in emulsion (liquid) form is to reduce its viscosity while ensuring the emulsion remains stable during storage and transportation. However, when applied to mineral fillers or road surfaces, it must break at a predetermined rate. The breaking rate mainly depends on the type of surfactant used and the grade of bitumen (Wang, Z., Wang, Q., and Ai, T., 2014).

Method and materials

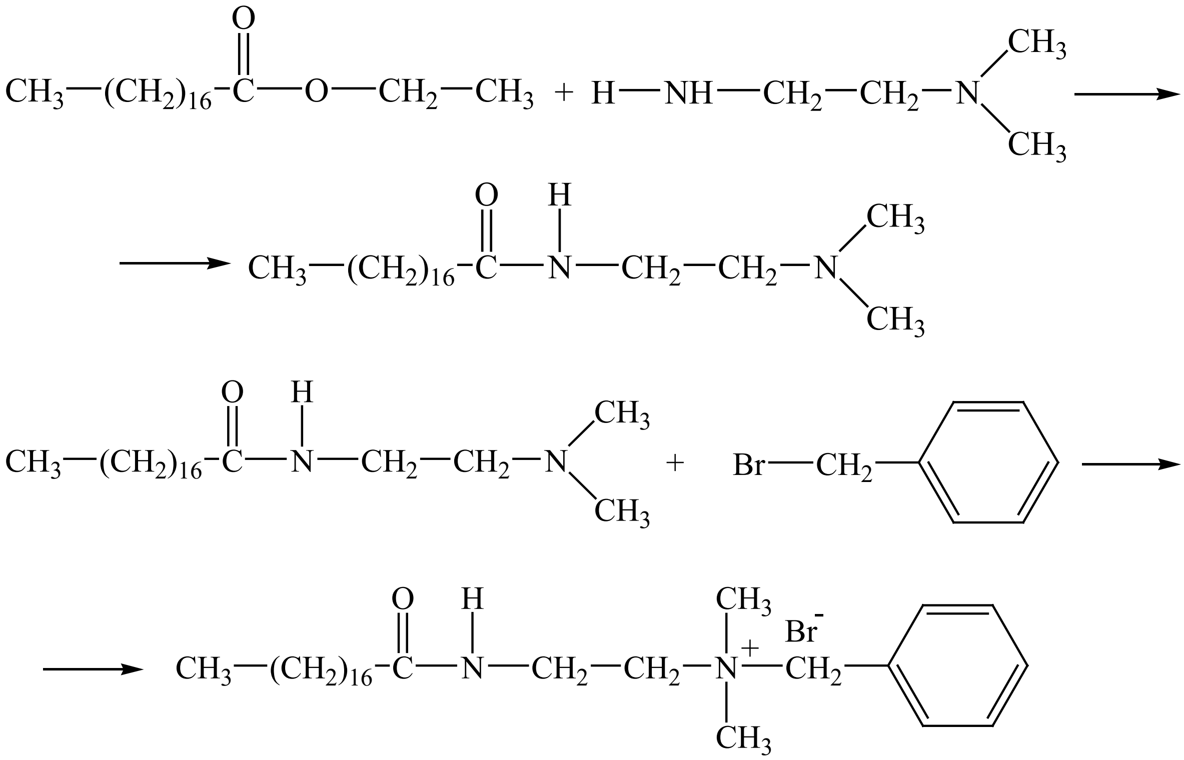
For the preparation of polymer-bitumen emulsions under laboratory conditions, synthesized cationic surfactants were modified and used along with bitumen, water, an emulsifier, hydrochloric and phosphoric acids, adhesion polymers, and a colloid mill. In the initial stage, 350 ml of water was heated to 50 °C, followed by the addition of 2.5 cm^3 of the synthesized cationic emulsifier and 1 cm^3 of phosphoric and hydrochloric acids until the pH reached 1.8–2.5. The bitumen was heated to 140°C and introduced into the colloid mill along with the prepared aqueous emulsifier solution. As a result, a polymer-bitumen emulsion was obtained, and its physicochemical and rheological properties were studied.

The physicochemical properties of synthesized cationic surfactants and the polymer-bitumen emulsions obtained through their modification were analyzed using the IRAffinity-1S Fourier Transform Infrared (FTIR) Spectrophotometer (Shimadzu). Methods were also employed to determine the viscosity of bitumen emulsions and to analyze the physicochemical properties of the residue left after water evaporation from the bitumen emulsion (Ludwig A.C., 1992).

Results

The synthesis of cationic surfactants consists of two stages, and in each stage, the effect of catalyst consumption and catalyst quantity on the reaction yield was determined. The reaction equation for the synthesis of cationic surfactants is presented in Figure 1.

Figure 1. *Stearamide cationic surfactant synthesis reaction*

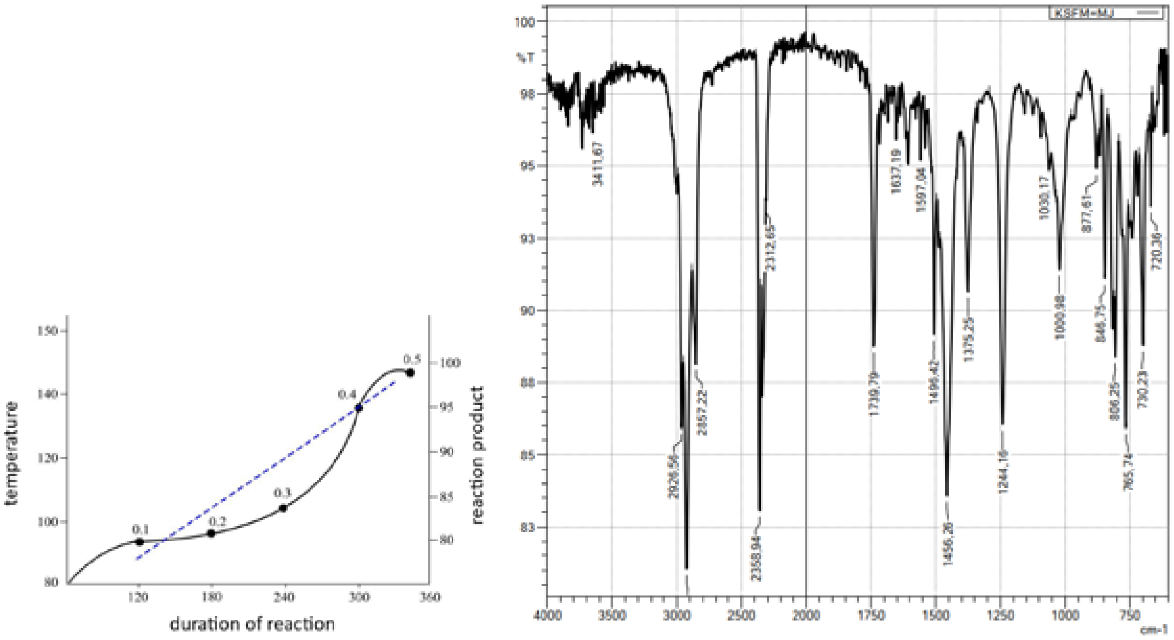


The graph in (Figure 2 a) illustrates the effect of temperature (80–120°C) and reaction time (6–9 hours) on reaction yield, ranging from 80% to 95%. It explains how higher temperatures and longer reaction times influence reaction efficiency, with the yield determined to be 89.7%. The factors affecting the reaction yield between N,N-dimethyl stearamide and benzyl bromide (temperature, catalyst, and time) are presented. The graph, with theoretical values, indicates that temperature and catalyst have the most significant impact, highlighting that optimizing these parameters is crucial for improving reaction efficiency.

The spectra in (Figure 2 b) show absorption regions corresponding to various functional groups. The absorption at 720.36–730.4 cm^{-1} is attributed to the CH_2 δ deformation of the sp^3-hybridized saturated alkyl group in stearic acid. The peaks at 806.25–846.75 cm^{-1} correspond to the benzene ring in the benzyl molecule, while the absorption at 1000.98 cm^{-1} is assigned to δ C-H in the aromatic ring and hydrogen-bonded structures in long-chain compounds. The range of 1244.10–13751.23 cm^{-1} corresponds to weakly active CH_2 stretching vibrations. The peak at 1400.82 cm^{-1} is attributed to νC-N stretching of N,N-dimethylethylenediamine derivatives substituted with ethyl stearate. The absorptions at 1456.26 cm^{-1} (δC-H) and 1496.42 cm^{-1} (ν benzene ring) confirm the presence of aromatic structures.

Figure 2: *a) The effect of temperature, reaction duration, and catalyst on BSA-K reaction yield b) Infrared spectra absorption peaks*

a) *b)*



The peak at 1597.04 cm^{-1} corresponds to δN-H bending of the secondary amide group, while the range 1637.19-1739.79 cm^{-1} is assigned to νC=O stretching of the carbonyl group. Further, absorptions at 2857.52 cm^{-1} indicate νCH_3 stretching vibrations of the methyl group, and at 2926.56 cm^{-1}, the presence of a quaternary nitrogen group linked to the benzyl group and N,N-dimethylethylenediamine molecule is observed. The peak at 3411.67 cm^{-1} corresponds to the νN-H stretching of a secondary amide with moderate intensity.

For the preparation of high-quality bituminous emulsion, the synthesized benzyl stearamide was used in a concentration range of 0.5–1.5%, with the bitumen phase constituting 45–50%. The composition of the bitumen emulsions and their physical-mechanical properties are presented in (Tables 1 and 2).

Table 1. *The composition of modified bitumen emulsions with synthesized cationic surfactants*

PBE samples.	**The composition of modified polymer-bitumen emulsions**					
1 l (PBE)	**Bitumen BND 50/70 %**	**KSFM (BSA-K) %**	**Stabilizer (CaCl$_2$) %**	**(HCl) %**	**Polymer (SBS) %**	**Kerosene %**
Sample 1	45	0,5	0,1	0,3	–	0,8
Sample 2		1,0	0,3	0,6	–	1,2
Sample 3		1,5	0,5	0,9	–	1,0
Sample 4		0,5	0,1	0,3	0,5	1,5
Sample 5		1,0	0,3	0,6	0,8	1,2
Sample 6		1,5	0,5	0,9	1,2	1,0
The rest is water (100%)						

Table 2. *Physico-mechanical properties of polymer-bitumen emulsions modified with cationic surfactants*

Composition of components	Indicators of polymer-bitumen emulsions based on synthesized BSA-K modification				
1 l (PBE)	**pH**	**Conditional viscosity at 40°C, c**	**Adhesion with mineral materials, %.**	**Homogeneity (%), according to sieve № 014**	**Storage stability % After 7 days**
Sample 1	1,85	19,2	85,0	0,25	0,30
Sample 2	2,05	17,4	87,0	0,20	0,28
Sample 3	2,10	16,6	89,0	0,20	0,25
Sample 4	2,24	37,9	87,0	0,30	0,21
Sample 5	2,38	33,1	92,0	0,35	0,15
Sample 6	2,32	29,4	98,0	0,35	0,09

PBE containing 45% bitumen

Discussion

As seen in this table, the pH level of various samples of rapidly breaking polymer-bitumen emulsions ranged from 1.85 to 2.38, the conditional viscosity from 19.2 to 41.1, adhesion to mineral materials from 85% to 100%, and homogeneity (uniformity) from 0.2 to 0.35. To prevent bitumen particle coalescence, BSA-K was added to water before preparing polymer-bitumen emulsions. During the bitumen dispersion process, BSA-K was distributed over the surface of bitumen particles, preventing coagulation of the obtained bitumen emulsions during storage. In cationic BSA-K bitumen emulsions, positively charged ions were oriented on the surface of bitumen droplets, while negatively charged chloride ions were attracted to the positive charges, leading to the formation of an electric double layer within the emulsion. The stability of bitumen emulsions during storage is determined by the rate of stratification. Stratification occurs under the influence of gravitational force and the difference in density between the two phases. Research results showed that increasing the BSA-K content to 0.5–1.5% and the bitumen content in emulsions up to 45–50% prevented droplet coalescence and increased their mobility. Additionally, the inclusion of kerosene as a solvent and maintaining the pH level between 2.0 and 2.4 helped prevent phase separation.

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