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THE INFLUENCE OF DIFFERENT SURFACTANTS ON THE RHEOLOGICAL BEHAVIOR OF GUM ARABIC

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ABSTRACT

This research aimed to assess how two different surfactants, Cetyl Trimethyl Ammonium Bromide (CTAB) and Sodium Dodecyl Sulfate (SDS), influenced the rheological properties of aqueous solution of Gum Arabic, the natural polymer. Using an Anton Paar Rheometer (MCR-102 Series), substantial changes in apparent viscosity, flow behavior properties, and shear thinning characteristics of the solution were observed. These changes were implemented through systematic modifications of the quantities of Gum Arabic. This study's findings offer significant understanding through the interactions between surfactants and natural polymers. The findings may be relevant in industries that employ polymer-surfactant combinations as thickening or thinning agents.

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1. INTRODUCTION

The interaction between surfactants and polymers in aqueous systems has garnered significant interest because of its broad applicability in industries such as food Mudgil et al. (2014), pharmaceuticals Mohsenipour and Pal (2013), and petrochemicals Hasan and Abdel-Raouf (2018). Among these polymers, Gum Arabic, a complex, amphiphilic polysaccharide, derived from Acacia species is extensively utilized as a stabilizer, emulsifier, and thickening agent due to its unique structural composition and functional versatility Patel and Goyal (2014). Understanding the molecular interactions between Gum Arabic and surfactants, and their influence on bulk rheological properties, is critical for optimizing formulation performance across various applications Abel et al. (2020). Gum Arabic exhibits complex rheological behavior in aqueous solutions, driven by its heterogeneous molecular weight distribution, branching, and associated protein components SY and WF (2017). Surfactants can bind to these macromolecular domains, inducing aggregation, conformational transitions, or the formation of polymer-surfactant complexes that modify solution viscosity and viscoelasticity Atgié et al. (2018). These interactions are surfactant-specific, anionic surfactants such as SDS typically exhibit stronger binding affinity toward hydrophobic polymer segments compared to non-ionic counterparts, leading to distinct rheological outcomes Pisarčik and Bakoš (1994). Such polymer-surfactant systems are widely employed in drug delivery, cosmetics, and enhanced oil recovery Yang and Pa (2020), where temperature and composition-dependent phenomena such as phase separation and gelation play a critical role Hansson and Lindman (1996); Kralova and Sjöblom (2009).Surfactants influence rheological parameters such as viscosity, elasticity, and yield stress. At low concentrations, surfactant adsorption increases the effective hydrodynamic volume of polymer chains, enhancing viscosity; however, at higher concentrations, micelle formation and electrostatic screening may reduce intermolecular interactions and lower viscosity Ye et al. (2017). These effects are modulated by surfactant charge density, ionic strength, and thermal conditions Kwak (2018). Additionally, polymer-surfactant complexes can form gel-like networks, significantly altering system texture and stability attributes critical to food and pharmaceutical formulations.

Emulsion stability is another area impacted by Gum Arabic–surfactant interactions. Gum Arabic stabilizes emulsions by adsorbing at the oil–water interface and preventing droplet coalescence Atgié et al. (2019). However, surfactants may either enhance or disrupt this stabilization, depending on their interfacial activity and concentration. Competitive adsorption can displace Gum Arabic from the interface, destabilizing the emulsion, while synergistic interactions can improve interfacial film strength and stability Kralova and Sjöblom (2009); Nesterenko et al. (2014). For example, SDS, a widely used anionic surfactant, interacts with polymers to substantially alter rheological behavior Milanović et al. (2021). Anionic surfactants derived from sulfonated ricinoleic acid methyl esters have also demonstrated the ability to reduce interfacial tension to ultra-low levels, aiding enhanced oil recovery through improved wettability and mobility control Babu et al. (2015); Oyatobo et al. (2021).

In this study, we investigated the influence of temperature and surfactant concentration on the apparent viscosity of Gum Arabic solutions containing sodium dodecyl sulfate (SDS, anionic) and cetyltrimethylammonium bromide (CTAB, cationic) under constant shear conditions. Five concentrations, ranging from 1000 to 5000 ppm, were used to prepare the solutions, which were then tested at 20, 30, 40, and 50 °C.

The main aim was to describe the interplay between ionic surfactant type, thermal conditions, and concentration on the rheological behavior of Gum Arabic solutions. A proposed theoretical model was used to support the interpretation of experimental results Barnes (1997). This work provides valuable insights into polymer–surfactant interactions and contributes to the rational design of Gum Arabic-based formulations for food, pharmaceutical, and industrial applications.

2. EXPERIMENTAL

This study utilized Gum Arabic, a high molecular weight polymer, procured from Dutt Enterprise, Nadiad, Gujarat, India. Two commercial reference surfactants, specifically sodium dodecyl sulfate (SDS) and cetyl trimethyl ammonium bromide (CTAB). Analytical grade pure SDS and CTAB were used and purchased from Dutt Enterprise located in Nadiad, India.

3. METHODS

3.1. POLYMER SOLUTION PREPARATION

A specified amount of Gum Arabic powder was mixed into 100 ml of water at 30 °C, with vigorous stirring for 1 to 2 minutes. The stirring process was maintained for at least about 3-4 hours at 500-600 rpm using a magnetic stirrer. The temperature was reduced to improve the hydration rate, leading to an increase in solution viscosity. Various concentrations of Gum Arabic solutions were prepared to assess the viscosity of each solution.

3.2. RHEOLOGICAL MEASUREMENTS

The solution viscosity involving Gum Arabic and blend of surfactant-polymer-surfactant at different concentrations was meticulously assessed by analyzing their reaction to shear rate (γ) using a cone and plate measurement setup with the Anton Paar Rheometer MCR 102 series. A temperature sweep study was performed under controlled circumstances, with a constant shear rate of 50 S^{-1}, throughout a temperature range of 20 to 50 °C. Constant Shear rate (CSR) study was performed at a fixed shear rate of 50 S^{-1} with varying temperature range of 20,30,40 and 50 °C. This work evaluated the rheological properties of the solutions to comprehend the variations in viscosity relative to shear rate, offering understanding of the flow properties of these complicated systems.

4. RESULT AND DISCUSSION

4.1. APPARENT VISCOSITY OF GUM ARABIC IN WATER SOLUTION

At a constant shear rate of 50 S^{-1}, the viscosity of Gum Arabic in aqueous solutions at concentrations of 1000, 2000, 3000, 4000, and 5000 ppm was measured. The temperature range in which the measurements were made was 20 to 50 °C. Figure 1 displays the data. This investigation aimed to analyze the changes in viscosity in relation to concentration and temperature. The findings, which are shown in Figure 1, reveal an evident correlation between the concentration of Gum Arabic in water and the solution's viscosity. With increased Gum Arabic concentrations, the viscosity rises noticeably.

Figure 1

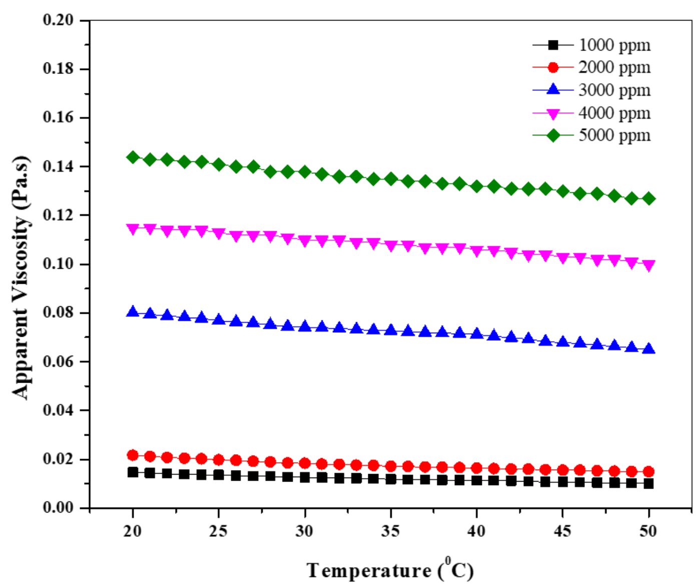


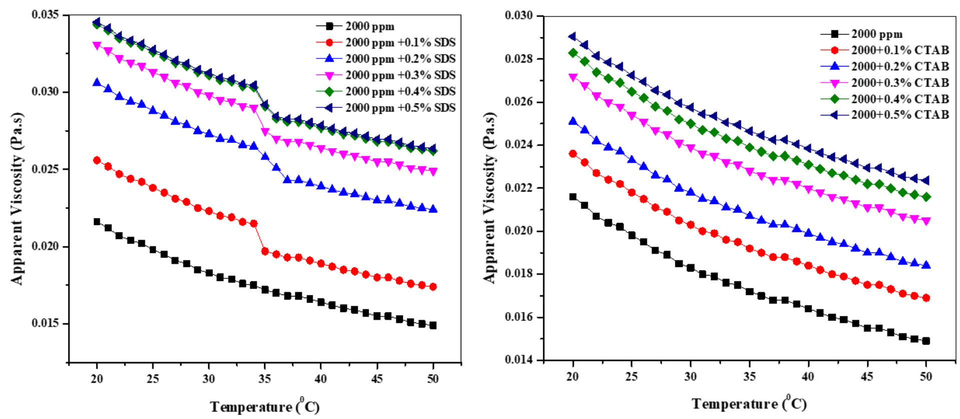
Figure 1 Influence of temperature on apparent viscosity of Gum Arabic Solution

All five tested concentrations showed a similar pattern of increasing viscosity with greater Gum Arabic solution concentrations. This phenomenon results from the increased concentration, which offers a greater number of polymer chains, thus improving interactions and entanglements among them Akbari et al. (2017). No significant reduction in apparent viscosity is observed with increasing temperature. The variation in apparent viscosity with rising temperature was negligible, exhibiting only a minor decrease as temperature increased. The stability of the solution has been proven across varying temperatures.

4.2. APPARENT VISCOSITY OF GUM ARABIC WITH SDS AND CTAB IN WATER SOLUTION

Figure 2(a) and 2(b) demonstrates the impact of varying concentrations of two distinct ionic surfactants, SDS and CTAB, on the apparent viscosity of a 2000 ppm Gum Arabic solution in water. The data indicate that incorporating surfactants into the Gum Arabic solution leads to an increase in apparent viscosity. Furthermore, an increase in surfactant concentration leads to a corresponding rise in the apparent viscosity of the Gum Arabic solution with varying concentrations of CTAB, as shown in Figure 2 (b). No notable changes in the pattern of apparent viscosity were noticed with increasing temperature, suggesting the solution stability in the presence of CTAB.

Figure 2



(a) (b)

Figure 2 (a) Influence of SDS on apparent viscosity of 2000 ppm Gum Arabic
(b) Influence of CTAB on apparent viscosity of 2000 ppm Gum Arabic

The solution of Gum Arabic with varying concentrations of SDS demonstrates a notable steep fall in apparent viscosity within the temperature range of 34 to 35 °C, as illustrated in Figure 2 (a). This occurs as a result of thermal variations in polymer surfactant aggregates.

4.3. A COMPARISON OF THE APPARENT VISCOSITY OF 2000 PPM GUM ARABIC WITH 0.1% SDS AND 0.1% CTAB IN AQUEOUS SOLUTIONS

Figure 3

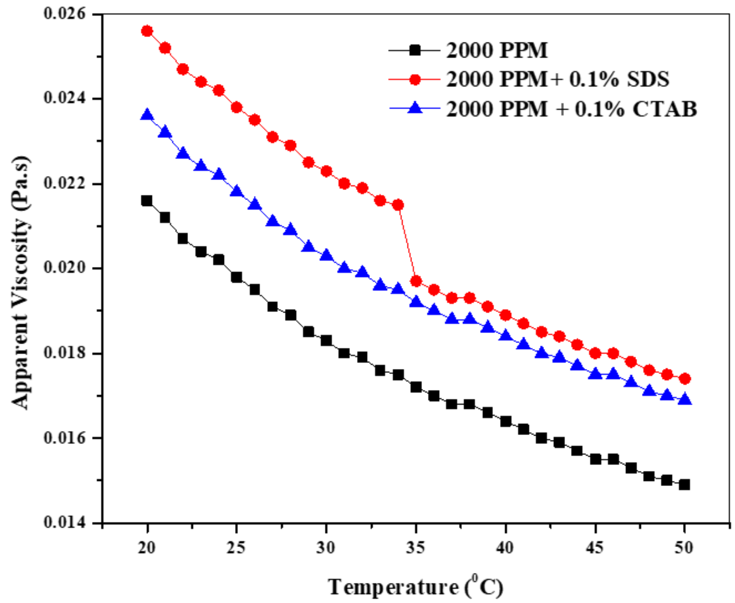


Figure 3 A Comparison of the apparent viscosity of a 2000 ppm Gum Arabic solution, both with and without presence of 0.1% SDS and 0.1% CTAB

Gum Arabic is a neutral polysaccharide characterized by the presence of hydroxyl groups, which enable the formation of hydrogen bonds. Anionic surfactants such as SDS exhibit strong interactions with hydroxyl groups via electrostatic interactions and hydrogen bonding, resulting in notable changes to the structure of polymer with rise in viscosity up to 35 °C. At a temperature of 35 °C, electrostatic interactions weaken slightly; however, the viscosity increases significantly when compared to polymer solutions without surfactant addition. Cationic surfactants, such as CTAB, exhibit weaker interactions with the hydroxyl groups in Gum Arabic compared to SDS.

The lowered electrostatic interactions diminish the efficacy of cationic surfactants in altering the polymer network, resulting in a lesser increase in viscosity.

4.4. NON-NEWTONIAN BEHAVIOR STUDY OF GUM ARABIC SOLUTION AT SPECIFIC TEMPERATURE AND CONCENTRATION

Over a temperature range of 20 to 50 °C, the rheological parameters of Gum Arabic solutions at concentrations ranging from 1000 to 5000 ppm, in the presence of surfactants SDS and CTAB, were evaluated. The correlation between shear stress and shear rate was studied by conducting Constant Shear Rate (CSR) analysis. The rheological model, namely the Herschel-Bulkley model, was utilized to investigate the non-Newtonian behavior of the solutions. This model was used to calculate experimental data, and the resulting parameters such as the flow consistency index (k) and the flow behavior index (n) are shown in tabular form.

Table 1

Table 1 The Impact of Temperature and Concentration on the Rheological Parameters of Gum Arabic Solution Calculated Using the Herschel-Bulkley Model

Concentration (PPM)	Temperature (°C)	Flow Behavior index (n)	Flow Consistency (k)
1000 PPM GUM ARABIC	20	0.782	0.0649
	30	0.827	0.0545
	40	0.874	0.0512
	50	0.931	0.0436
2000 PPM GUM ARABIC	20	0.729	0.0675
	30	0.751	0.0612
	40	0.815	0.0527
	50	0.853	0.0481
3000 PPM GUM ARABIC	20	0.567	0.0741
	30	0.593	0.0654
	40	0.632	0.0583
	50	0.675	0.0524
4000 PPM GUM ARABIC	20	0.448	0.0775
	30	0.479	0.0689
	40	0.527	0.0554
	50	0.577	0.0492
5000 PPM GUM ARABIC	20	0.354	0.082
	30	0.408	0.0712
	40	0.472	0.0581
	50	0.521	0.0471

The flow consistency index (k) and flow behavior index (n) values obtained from Constant Shear Rate (CSR) study using an Anton Paar Rheometer (model MCR 102 series) at a constant shear rate of 100 S^{-1} are shown in Table 1. The flow behavior index (n) for Gum Arabic solutions typically decreases with higher polymer concentration and increases with elevated temperature. This behavior suggests that solutions exhibit increased shear-thinning properties at elevated polymer concentrations and temperatures. The observed changes result from increased entanglements and interactions among polymer chains at higher concentrations, affecting the shear-thinning properties of the solutions.

Table 2

Table 2 The Impact of Temperature and Concentration on Rheological Properties of Gum Arabic with 0.2 wt% SDS Calculated using Herschel Bulkley Model

Concentration (PPM)	Temperature (°C)	Flow behavior index (n)	Flow Consistency (k)
1000 PPM Gum Arabic + 0.2% SDS	20	0.716	0.0688

	30	0.742	0.0627
	40	0.791	0.0584
	50	0.847	0.0514
2000 PPM Gum Arabic + 0.2% SDS	20	0.658	0.0746
	30	0.693	0.0652
	40	0.771	0.0581
	50	0.814	0.0519
3000 PPM Gum Arabic + 0.2% SDS	20	0.524	0.0789
	30	0.569	0.0716
	40	0.605	0.0634
	50	0.646	0.0571
4000 PPM Gum Arabic + 0.2% SDS	20	0.414	0.0834
	30	0.456	0.0754
	40	0.483	0.0616
	50	0.529	0.0544
5000 PPM Gum Arabic + 0.2% SDS	20	0.306	0.0851
	30	0.335	0.0771
	40	0.384	0.0632
	50	0.449	0.0525

Table 2 displays the calculated values of the flow behavior index (n) and flow consistency index (k) of Gum Arabic solutions at concentrations between 1000 and 5000 ppm, incorporating 0.2% SDS. This research aims to examine the effect of SDS surfactant on the rheological properties of Gum Arabic solutions. The results demonstrate that the addition of a constant concentration of SDS to varying concentrations of Gum Arabic solutions typically leads to a decrease in the flow behavior index (n) and may result in an increase in the flow consistency index (k). The interaction between SDS and Gum Arabic is responsible for this trend, typically resulting in increased viscosity of the solutions.

Table 3

Table 3 The impact of Temperature and Concentration on Rheological Properties of Gum Arabic Solution with 0.2 wt% CTAB calculated using Herschel Bulkley Model

Concentration (PPM)	Temperature (°C)	Flow behavior index (n)	Flow Consistency (k)
1000 PPM Gum Arabic + 0.2 wt% CTAB	20	0.739	0.0633
	30	0.772	0.0571
	40	0.821	0.0507
	50	0.877	0.0441
2000 PPM Gum Arabic + 0.2 wt% CTAB	20	0.682	0.0682
	30	0.729	0.0609
	40	0.801	0.0536
	50	0.844	0.0475

3000 PPM Gum Arabic + 0.2 wt% CTAB	20	0.562	0.0752
	30	0.601	0.0668
	40	0.65	0.0596
	50	0.698	0.0528
4000 PPM Gum Arabic + 0.2 wt% CTAB	20	0.444	0.0791
	30	0.392	0.0686
	40	0.349	0.0561
	50	0.311	0.0495
5000 PPM Gum Arabic + 0.2 wt% CTAB	20	0.337	0.0819
	30	0.371	0.0726
	40	0.418	0.0598
	50	0.475	0.0479

Table 3 displays the calculated values of the flow behavior index (n) and flow consistency index (k) of Gum Arabic solutions ranging between 1000 and 5000 ppm, incorporating with the presence of 0.2 wt% CTAB. The main purpose of this study was to observe the effect of CTAB surfactant on the rheological properties of Gum Arabic solutions. The data obtained from this study suggest that the addition of CTAB in fixed concentration to varying concentrations of Gum Arabic typically leads to a decrease in the flow behavior index (n) and results in a rise in the flow consistency index (k). Less intense interactions between CTAB molecules and Gum Arabic molecules are indicated by the higher values of the flow behavior index (n) observed with CTAB compared to SDS. The polymer network is modified less effectively as a consequence of the decreased interaction, leading to an increased flow behavior index (n) that indicates a reduced shear-thinning behavior in comparison to SDS.

5. CONCLUSION

This work investigates the rheological characteristics of Gum Arabic solutions in the presence of two distinct ionic surfactants: sodium dodecyl sulfate (SDS) and cetyl trimethyl ammonium bromide (CTAB). The study offered important insights into the formulation and optimization of Gum Arabic solutions in relation to surfactants like SDS and CTAB, particularly in situations where changes in viscosity are crucial. The research underscores the critical influence of temperature and concentration on the apparent viscosity of solution of Gum Arabic, particularly in context of presence of surfactant. According to the comparison investigation, Gum Arabic solutions including SDS had a higher apparent viscosity than solutions containing CTAB. The findings demonstrate that both systems display non-Newtonian characteristics, specifically shear-thinning flow behavior. The rheological findings highlight the substantial interaction between Gum Arabic and SDS, resulting in a pronounced rise in viscosity, whereas the contact with CTAB is comparatively less. The results elucidate the interactions between Gum Arabic and the surfactants SDS and CTAB, emphasizing their potential uses in industries requiring precise viscosity control.

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