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An Impact of Various Surfactants on The Rheological Action of Xanthan Gum.

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ABSTRACT

This study investigates the influence of two different types of surfactants, specifically Sodium Dodecyl Sulfate (SDS) and Cetyl Trimethyl Ammonium Bromide (CTAB), on the rheological properties of aqueous solutions of the natural polymer, Xanthan Gum. By systematically varying the concentrations of Xanthan Gum, we observed significant modifications in viscosity, flow behavior, and shear thinning characteristics of the solutions, utilizing an Anton Paar MCR 102 series rheometer. The results from this research provide valuable insights into the interactions between surfactants and natural polymers, with potential applications in industries where polymer-surfactant blends are used as thickening or thinning agents.

Keywords: Xanthan Gum, Sodium dodecyl sulphate (SDS), Cetyl trimethyl ammonium bromide (CTAB), Rheology, Apparent Viscosity, Shear thinning

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INTRODUCTION

The interaction between surfactants and polymers in aqueous solutions has gained considerable attention in recent decades due to its broad industrial applications, including in the food industry [1], pharmaceuticals and drug delivery systems [2], and petrochemicals [3]. Xanthan gum is a high molecular weight polysaccharide produced through the pure-culture fermentation of carbohydrates using strains of Xanthomonas campestris. The structure of xanthan gum polysaccharide features a backbone of β-(1→4) linked D-glucose molecules. Every alternate glucose unit is substituted at the C_3 position with a trisaccharide side chain. This side chain is composed of β-D-mannose-(1→4)-β-D-glucuronic acid-(1→2)-α-D-mannose. In these side chains, the terminal mannose unit is partially modified with a pyruvate residue linked as an acetal to the 4 and 6 positions, while the internal mannose unit is acetylated at the C_6 position [3]. Xanthomonas, a genus of Gram-negative, rod-shaped aerobes within the family Pseudomonadaceae, encompasses several species that produce xanthan gum, although many are also phytopathogens [4]. Commercially, up to 70% of the substrate can be converted into xanthan gum through aerobic fermentation, conducted at temperatures ranging from 27 to 30 °C, with organic acids serving as stimulants [5,6].

Xanthan gum is widely utilized in the food industry as an emulsifier and stabilizer, with additional applications in the oil, cosmetic, textile, and paper industries [7]. Enhancing xanthan production and optimizing factors that increase its yield, such as surfactants, have garnered significant interest [8]. Detergents can enhance oxygen transfer, thereby improving xanthan production and its rheological properties, including viscosity [9,10]. Furthermore, the application of detergents facilitates the increased production of hydrolyzing enzymes [11-14], although the underlying mechanisms remain largely unclear. Potential mechanisms include increased cell membrane permeability, altered lipid metabolism, and enhanced enzyme release [11-14]. Surfactants impact bacterial membranes, particularly by disrupting the less-selective outer membrane [9, 10, 15], which, in this context, leads to improved release of xanthan gum. Surfactants, due to their ability to reduce surface tension, significantly influence the physicochemical properties of solutions, particularly in the presence of polymers. Anionic surfactants, such as sodium dodecyl sulfate (SDS), interact with polymers, resulting in notable alterations in the solution's behavior [16]. The sulfonation of ricinoleic acid methyl ester derived from castor oil produces anionic surfactants that effectively reduce interfacial tension (IFT) to ultra-low levels while enhancing rock wettability [17]. The efficient displacement of entrapped oil within internal structures such as cracks, crevices, and pores are dependent on the synergistic interaction between surfactants and polymers, which aims to enhance sludge integrity, optimize adsorption, and provide effective control over mobility [18].

This study aims to investigate the effect of temperature and concentration on the apparent viscosity of Xanthan Gum solutions containing anionic surfactant SDS and cationic surfactant CTAB at a constant shear rate. Solutions of Xanthan Gum with SDS and CTAB were prepared at five different concentrations, ranging from 1000 to 5000 ppm. Apparent viscosity measurements were conducted at four distinct temperatures: 20, 30, 40, and 50 °C. The objective was to elucidate the interaction between temperature, concentration, and viscosity in these solutions. To enhance the understanding and predictive capability of this behavior, one theoretical model was employed [19]. This research investigates the impact of two different ionic groups of surfactants on the rheological behavior of Xanthan Gum solutions. By examining these interactions, we aim to elucidate the effects and provide a comprehensive understanding that could facilitate the optimization of formulations across various applications.

EXPERIMENTAL

Materials

The polymer used in this study was Xanthan Gum, a high molecular weight compound with a viscosity ranging from 5200 to 5500 cP, sourced from Dutt Enterprise, Nadiad, India.

Commercial benchmark surfactants, sodium dodecyl sulfate (SDS) and cetyl trimethyl ammonium bromide (CTAB), were utilized in this study. Extra pure SDS and CTAB were procured from Dutt Enterprise in Nadiad, India.

Methods

Polymer solution preparation

To prepare the Xanthan Gum solution, a predetermined quantity of Xanthan Gum powder was introduced into 100 ml of water at 30 °C, followed by continuous stirring for 1 to 2 min. The stirring process was sustained for a minimum of 3-4 hours at 500-600 rpm using a magnetic stirrer. Then it was kept at a lower temperature to increase the rate of hydration which increased the viscosity of the solution. Various concentrations of Xanthan Gum solutions were prepared to assess the viscosity of each solution.

Rheological Measurements

The viscosity of solutions containing Xanthan Gum and polymer-surfactant blends at various concentrations was systematically examined by monitoring their response to shear rate (γ) using cone and plate type measuring system with Anton Paar Rheometer MCR 102 series. A temperature sweep analysis was conducted under controlled conditions, maintaining a constant shear rate of 50 S^{-1} in the temperature range from 20 to 50 °C. Constant Shear Rate (CSR) analysis was also performed at constant shear rate of 100 S^{-1} for the temperature 20, 30, 40 and 50 °C.

Throughout this study, the rheological behavior of the solutions was assessed to understand how viscosity changed in response to shear rate, providing insights into the flow characteristics of these complex systems.

RESULT AND DISCUSSION

Apparent viscosity of Xanthan Gum in water solution

The viscosity of Xanthan Gum in aqueous solutions at concentrations of 1000, 2000, 3000, 4000, and 5000 ppm was measured under a constant shear rate of 50 $s^{-1.}$ These measurements were performed across a temperature range of 20 to 50°C. The resulting data are presented in Figure 1. The primary objective of this investigation was to examine the variations in viscosity as a function of both concentration and temperature. As illustrated in Figure 1, the results indicate a direct correlation between the concentration of Xanthan Gum in water and the viscosity of the solution. Specifically, the viscosity significantly increases with higher concentrations of Xanthan Gum.

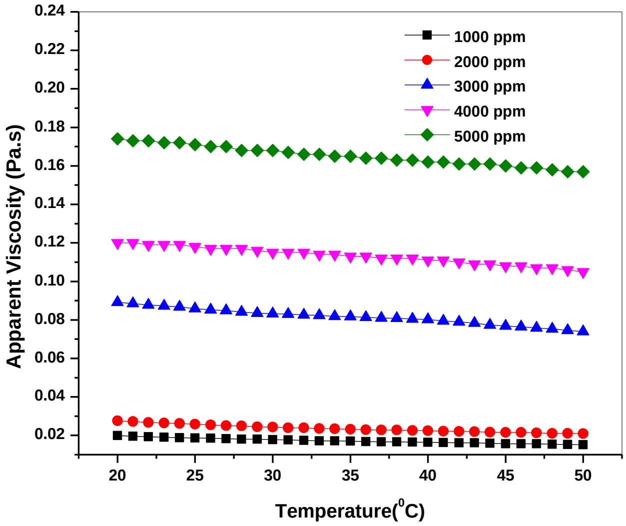
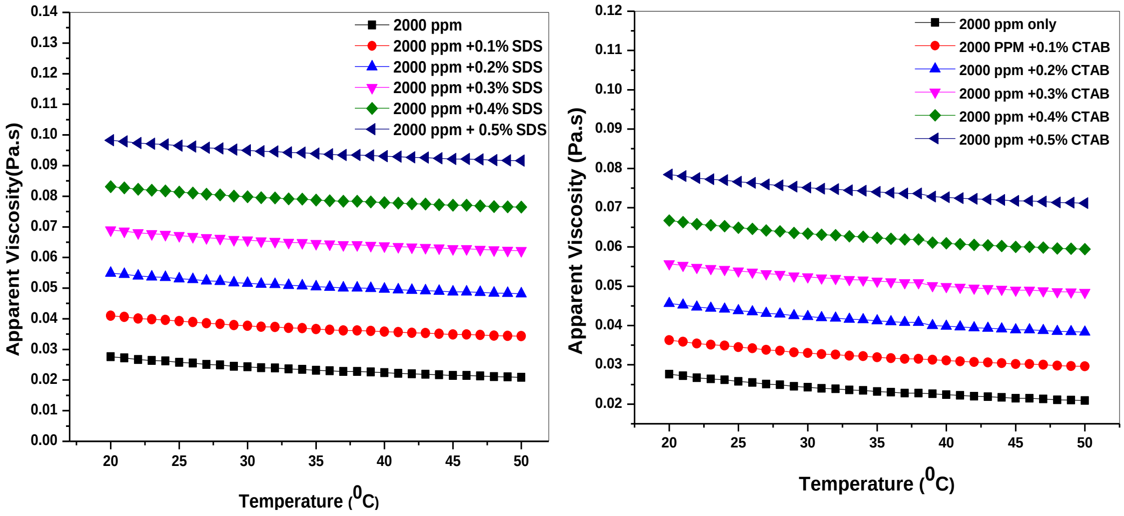


Figure 1: Effect of temperature on apparent viscosity of Xanthan Gum

A consistent trend of increased viscosity with higher Xanthan Gum concentrations was observed across all five concentrations tested. This phenomenon can be attributed to the higher concentration providing more polymer chains, thereby enhancing interactions and entanglements among these chains [20]. The change in apparent viscosity with increasing temperature was found to be minimal, with only a slight reduction observed as temperature increased.

Apparent viscosity of Xanthan Gum with SDS and CTAB in water solution



a **b**

Figure 2: (a) Effect of surfactant SDS on apparent viscosity of 2000 ppm Xanthan Gum
(b) Effect of surfactant CTAB on apparent viscosity of 2000 ppm Xanthan Gum

Figure 2 illustrates the effect of increasing concentration of two different ionic groups of surfactants (SDS and CTAB) on the apparent viscosity of a 2000 ppm Xanthan Gum solution in water. The data clearly demonstrate that the addition of surfactants to the Xanthan Gum solution results in an increase in viscosity. Moreover, as the concentration of surfactants increases, the viscosity of the solution progressively rises. No significant deviations in the trend of apparent viscosity were observed with increasing temperature, indicating the stability of the solution in the presence of surfactants.

Comparative study of apparent viscosity of 2000 ppm Xanthan Gum with 0.1 % SDS and 0.1% CTAB in aqueous solutions

Figure 3 presents a comparative analysis of the viscosity of a 2000 ppm Xanthan Gum solution with the addition of 0.1% SDS and 0.1% CTAB, respectively. The data clearly indicate that the addition of 0.1% SDS to the 2000 ppm Xanthan Gum solution results in a higher increase in viscosity compared to the addition of 0.1% CTAB.

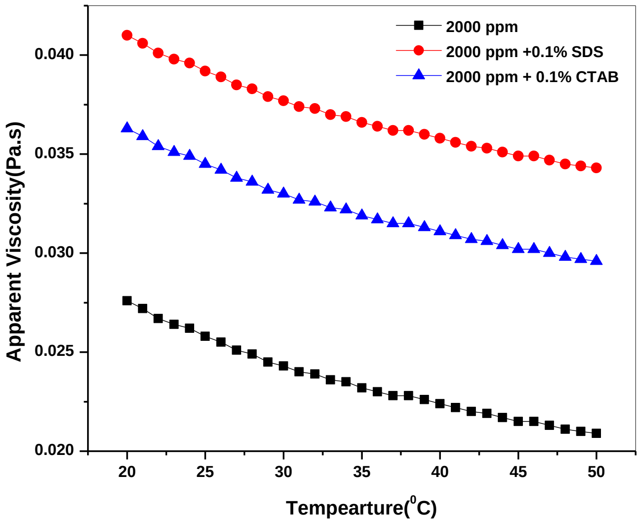


Figure 3: Comparative analysis of apparent viscosity of Xanthan gum with and without 0.1% SDS and 0.1% CTAB

Xanthan Gum, a neutral polysaccharide with hydroxyl groups, can form hydrogen bonds. Anionic surfactants like SDS interact strongly with these hydroxyl groups through electrostatic interactions and hydrogen bonding, leading to significant alterations in the polymer structure and an increase in viscosity. Conversely, cationic surfactants, such as CTAB, do not interact as strongly as SDS with the hydroxyl groups in Xanthan Gum. The weaker electrostatic interactions render cationic surfactants less effective at modifying the polymer network, resulting in a smaller increase in viscosity.

Comparative Study of apparent viscosity of 2000 ppm Xanthan Gum with SDS and CTAB in aqueous solutions at increasing concentrations

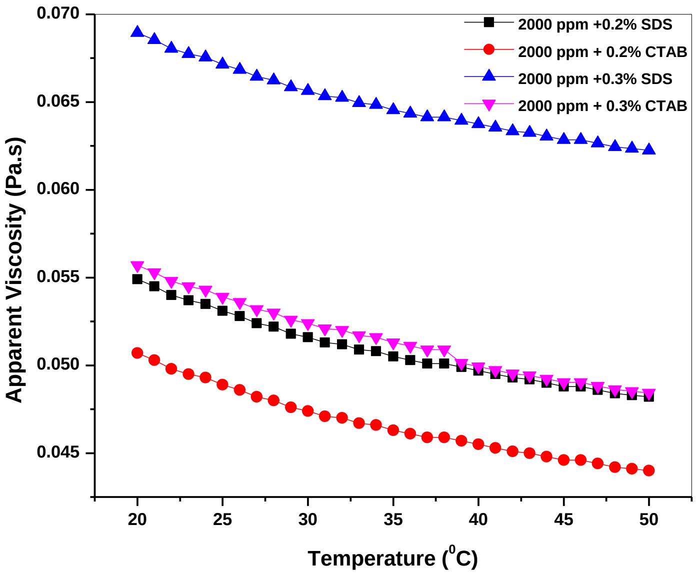


Figure 4: Comparative analysis of apparent viscosity of Xanthan gum with SDS and CTAB at increasing surfactant concentration.

Figure 4 presents the apparent viscosity analysis of a 2000 ppm Xanthan Gum solution with varying concentrations of SDS and CTAB. The data clearly demonstrate that the addition of surfactants to the Xanthan Gum solution results in an increase in viscosity. As the concentration of the surfactant increases, the viscosity of the polymer solution is further enhanced. Notably, the viscosity increase is more pronounced with the anionic surfactant SDS compared to the cationic surfactant CTAB. This suggests a stronger interaction between Xanthan Gum molecules and SDS compared to CTAB.

Non-Newtonian behavior study of Xanthan Gum with a specified Temperature and Concentration

The rheological parameters of Xanthan Gum solutions at concentrations ranging from 1000 to 5000 ppm with the surfactants SDS and CTAB were evaluated across a temperature range of 20-50 °C. Constant Shear Rate (CSR) analysis was performed to determine the relationship between shear stress and shear rate. Two different rheological models, the Herschel-Bulkley model and the Power Law model, were employed to study the non-Newtonian behavior of the solutions. The resulting parameters, including the flow behavior index and the flow consistency index, were derived from experimental data using these models and are tabulated accordingly.

Table 1: Effect of temperature and concentration on Rheological Properties of Xanthan Gum evaluated by Herschel Bulkley Model

Concentration (PPM)	Temperature (°C)	Flow Behavior index (n)	Flow Consistency (k)
1000 PPM XANTHAN GUM	20	0.70244	0.63619
	30	0.74278	0.55504
	40	0.79425	0.50256
	50	0.85142	0.43627
2000 PPM XANTHAN GUM	20	0.65498	0.67532
	30	0.68048	0.60215
	40	0.73871	0.53247
	50	0.77234	0.46841
3000 PPM XANTHAN GUM	20	0.48175	0.74521
	30	0.51303	0.66254
	40	0.55092	0.58253
	50	0.59507	0.52154
4000 PPM XANTHAN GUM	20	0.37154	0.78533
	30	0.40561	0.69192
	40	0.44967	0.55451
	50	0.49763	0.49237
5000 PPM XANTHAN GUM	20	0.28424	0.81247
	30	0.33095	0.71452
	40	0.38164	0.58118
	50	0.44099	0.47251

Table 1 presents the flow behavior index (n) and flow consistency index (k) values obtained from Constant Shear Rate (CSR) analysis conducted using an Anton Paar rheometer, specifically the MCR102 series, at a fixed shear rate of 100 S-1. The flow behavior index (n) for Xanthan Gum solutions generally exhibits a decreasing trend with increasing polymer concentration, while it shows an increasing trend with rising temperature. This behavior indicates that the solutions become more shear-thinning at higher polymer concentrations and temperatures. These changes are attributed to enhanced entanglements and interactions among polymer chains at elevated concentrations, thereby influencing the shear-thinning characteristics observed in the solutions.

Table 2: Effect of temperature and concentration on Rheological properties of Xanthan Gum with 0.2% SDS evaluated by Herschel Bulkley Model

Concentration (PPM)	Temperature (°C)	Flow behavior index (n)	Flow Consistency (k)
1000 PPM XANTHAN GUM + 0.2% SDS	20	0.64503	0.68833
	30	0.68863	0.60718
	40	0.74855	0.5547
	50	0.81602	0.48841
2000 PPM XANTHAN GUM + 0.2% SDS	20	0.59757	0.72746
	30	0.62633	0.65429
	40	0.69301	0.58461
	50	0.73694	0.52055
3000 PPM XANTHAN GUM + 0.2% SDS	20	0.42434	0.79735
	30	0.45888	0.71468
	40	0.50522	0.63467
	50	0.55967	0.57368
4000 PPM XANTHAN GUM + 0.2% SDS	20	0.31413	0.83747
	30	0.35146	0.74406
	40	0.40397	0.60665
	50	0.46223	0.54451
5000 PPM XANTHAN GUM + 0.2% SDS	20	0.22683	0.86461
	30	0.2768	0.76666
	40	0.33594	0.63332
	50	0.40559	0.52465

Table 2 presents the estimated values of the flow behavior index (n) and flow consistency index (k) for Xanthan Gum solutions ranging from 1000 to 5000 ppm, with the addition of 0.2% SDS. The primary objective of this study is to investigate the impact of SDS surfactant on the rheological characteristics of Xanthan Gum solutions. The findings indicate that adding a fixed concentration of SDS to increasing concentrations of Xanthan Gum solutions generally results in a reduction in the flow behavior index (n) and potentially an increase in the flow consistency index (k). This trend is attributed to the interaction between SDS and Xanthan Gum, which typically enhances the viscosity of the solutions.

Table 3: Effect of temperature and concentration on Rheological Properties of Xanthan Gum with 0.2% CTAB evaluated by Herschel Bulkley Model

Concentration (PPM)	Temperature (°C)	Flow behavior index (n)	Flow Consistency (k)
1000 PPM Xanthan Gum + 0.2% CTAB	20	0.67623	0.64333
	30	0.71983	0.56218
	40	0.77975	0.5097
	50	0.84722	0.44341
2000 PPM XANTHAN GUM + 0.2% CTAB	20	0.62877	0.68246
	30	0.65753	0.60929
	40	0.72421	0.53961
	50	0.76814	0.47555
3000 PPM XANTHAN GUM + 0.2% CTAB	20	0.45554	0.75235
	30	0.49008	0.66968
	40	0.53642	0.58967
	50	0.59087	0.52868
4000 PPM XANTHAN GUM + 0.2% CTAB	20	0.34533	0.79247
	30	0.38266	0.69906
	40	0.43517	0.56165
	50	0.49343	0.49951
5000 PPM XANTHAN GUM + 0.2% CTAB	20	0.25803	0.81961
	30	0.30812	0.72166
	40	0.36714	0.58832
	50	0.43679	0.47965

Table 3 presents estimated values of the flow behavior index (n) and flow consistency index (k) for Xanthan Gum solutions ranging from 1000 to 5000 ppm, with the addition of 0.2% CTAB. The study aims to examine how CTAB surfactant influences the rheological properties of Xanthan Gum solutions. The results indicate that adding a fixed concentration of CTAB to increasing concentrations of Xanthan Gum generally reduces the flow behavior index (n) and may increase the flow consistency index (k). The higher values of the flow behavior index (n) observed with CTAB compared to SDS suggest weaker interactions between CTAB molecules and Xanthan Gum molecules. This weaker interaction leads to less effective modification of the polymer network, resulting in a higher flow behavior index (n) indicative of less shear-thinning behavior compared to SDS.

CONCLUSION

In this study, we investigated the rheological behavior of Xanthan Gum solutions with the addition of two different ionic surfactants, sodium dodecyl sulfate (SDS) and cetyl trimethyl ammonium bromide (CTAB). This research provides critical insights for the formulation and optimization of Xanthan Gum with surfactants like SDS and CTAB, particularly in applications where viscosity control is essential. The study highlights the significant role of concentration and temperature in modulating the viscosity of Xanthan Gum, especially in the presence of these surfactants.

The comparative analysis revealed that the apparent viscosity of Xanthan Gum solutions with SDS is higher than those with CTAB. The results indicate that both systems exhibit non-Newtonian behavior characterized by shear-thinning flow phenomena. The rheological data underscore the strong interaction between Xanthan Gum and SDS, resulting in a more pronounced increase in viscosity, while the interaction with CTAB is comparatively weaker. These findings provide a comprehensive understanding of the varying interactions between Xanthan Gum and the surfactants SDS and CTAB, informing their potential applications in industries requiring precise viscosity control.

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