Uluslararası İleri Doğa Bilimleri ve Mühendislik Araştırmaları Dergisi
Sayı 7, S. 452-457, 4, 2023

Araştırma Makalesi

IJANSER

https://as-proceeding.com/index.php/ijanser
ISSN: 2980-0811

International Journal of Advanced Natural Sciences and Engineering Researches
Volume 7, pp. 452-457, 4, 2023

Research Article

Effects of Dispersion Medium on Surface Tension and Rheological Behavior of Pectin and Guar Gum Based Thickeners Used in Treatment of Dysphagia

Mukaddes Karataş[1] and Ercan Aydoğmuş[1*]

[1]*Department of Chemical Engineering, Engineering Faculty, Fırat University, 23119, Elazığ, Türkiye*

[*]*Email of corresponding author: ercanaydogmus@firat.edu.tr*

(Received: 11 May 2023, Accepted: 30 May 2023)

(DOI: 10.59287/ijanser.790)

(1st International Conference on Contemporary Academic Research ICCAR 2023, May 17-19, 2023)

ATIF/REFERENCE: Karataş, M., & Aydoğmuş, E. (2023). Effects of Dispersion Medium on Surface Tension and Rheological Behavior of Pectin and Guar Gum Based Thickeners Used in Treatment of Dysphagia. *International Journal of Advanced Natural Sciences and Engineering Researches,* 7(4), 452-457.

Abstract – Dysphagia is a complex condition as each individual may have unique swallowing difficulties and sensitivities. Experimental studies investigating the effects of dispersion media on thickeners can contribute to the development of customized thickening agents. Understanding how the dispersion environment affects the surface tension and rheological behavior of thickeners can lead to improved patient safety, comfort, and overall treatment efficacy by helping healthcare professionals make informed decisions when selecting appropriate thickening agents and optimizing their use in clinical practice. In this study, the effects of dispersion medium (water and lemonade) on the surface tension and rheology of thickened liquids prepared with pectin or guar gum-based thickening powders have been investigated. The rheological behaviors of the samples are determined at room temperature at the shear rate ranges of 10-100 s^{-1} using a rotary viscometer. Obtained data are modeled by Power Law and Herschel Bulkley. Both pectin and guar gum thickeners exhibit shear thinning behavior, meaning that their viscosity decreases under shear stress. The dispersion medium influences the degree of shear thinning observed. The low surface tension of this medium raises wetting and improves the dispersion of thickeners, resulting in faster dissolution and better mixing. This can be beneficial for the treatment of dysphagia as it allows for easier swallowing and better texture of thickened fluids.

Keywords – Viscosity, Dysphagia, Guar Gum, Pectin, Surface Tension, Rheological Behavior

I. INTRODUCTION

Dysphagia, used as a medical term to describe a swallowing disorder, refers to difficulties or abnormalities in the process of swallowing food and drink or even pills. Swallowing is a complex process that involves the coordination of various muscles and structures in the mouth, throat, and esophagus. When any part of this process is disrupted, it can lead to dysphagia [1-4].

Neurological conditions (stroke, Parkinson's disease, multiple sclerosis, amyotrophic lateral sclerosis (ALS), and muscular dystrophy), structural abnormalities (abnormalities in the structures of the throat, esophagus, or mouth), muscle disorders (weakness or dysfunction of the muscles related to swallowing), gastroesophageal reflux disease and aging-related swallowing function can be listed as some common causes of dysphagia [5-6].

Dysphagia can significantly impact a person's ability to consume an adequate and balanced diet, which can lead to malnutrition, dehydration, and other health complications. Individuals with this disease avoid drinking enough fluids because of difficulty swallowing, which increases the risk of dehydration. Adequate hydration is essential to maintain proper bodily functions. Managing fluid intake and ensuring that individuals with dysphagia consume adequate fluid is important to prevent dehydration and related complications. For swallowing safety, nutritional fluids should be thickened and fluid flow should be slowed down [7-9].

Thickening powders are commonly used in the treatment of dysphagia, which is a swallowing disorder characterized by difficulty in swallowing food and liquids. These powders are added to liquids to increase their viscosity or thickness, making it easier for individuals with dysphagia to swallow safely. Dysphagia can lead to the aspiration of liquids into the airway, which can cause choking or respiratory problems. By increasing the viscosity of liquids, thickening powders reduce the risk of aspiration by slowing down the flow and making it easier to control the bolus during swallowing [10-12].

An increase in the surface tension of the dispersion medium can lead to reduced wetting and slower dispersion of thickeners. This can result in longer dissolution times and difficulties in obtaining a homogeneous mixture. It is preferred in the treatment of dysphagia as a lower surface tension will result in a more homogeneous mixture, allowing easier swallowing and better texture of thickened liquids [14-15].

This study aims to investigate the effects of dispersion medium (water and lemonade) on the surface tension and rheology of thickened liquids prepared with pectin or guar gum-based thickening powders. It is thought that this study will provide a deeper understanding of the behavior of thickeners in different dispersion environments, support optimized dysphagia management and contribute to the scientific knowledge base in this important area of health care.

II. MATERIAL AND METHOD

Materials

In this study, guar gum in powder form (Tito, Smart Chemistry Inc., İzmir, Türkiye) and citrus pectin (Tito, Smart Chemistry Inc, İzmir, Türkiye) were used as thickeners. Both thickeners were used in food grade [27]. To investigate the effects of thickeners under neutral and acidic conditions, deionized water and a lemonade commonly used in Türkiye (Uludag, Uludag Beverage Inc., Bursa, Türkiye) were used. The pH of the deionized water and lemonade used as the dispersion medium were measured as 6.9 and 4.4, respectively, using a pH meter (Delta 350, Mettler Toledo, Schwerzenbach, Switzerland).

Preparation of thickened liquids

It was prepared by dissolving thickening powders in the chosen dispersion medium to prepare thickened liquids of different concentrations. To obtain a homogeneous solution, it was mixed with a magnetic stirrer (Weightlab Instruments, İstanbul, Türkiye) at medium speed for 3 hours at 25 °C and it was stored at 4 °C overnight to ensure complete hydration before rheological measurements.

IDDSI flow test

To consolidate UK standards for dysphagia and provide a standardized dietary framework, the International Dysphagia Dietary Standardization Initiative (IDDSI) introduced a new taxonomy at the end of 2015 to categorize by gravity flow. According to this new system, IDDSI levels (Fig. 1) were determined, with liquid foods classified as Level 0-4 and solid foods as Level 3-7 [16]. The IDDSI flow test was applied to the solutions prepared in different dispersion media after 10 mL of material was allowed to flow from a standard syringe (10 mL) for 10 seconds, then the liquids were classified according to the remaining liquid volume [17].

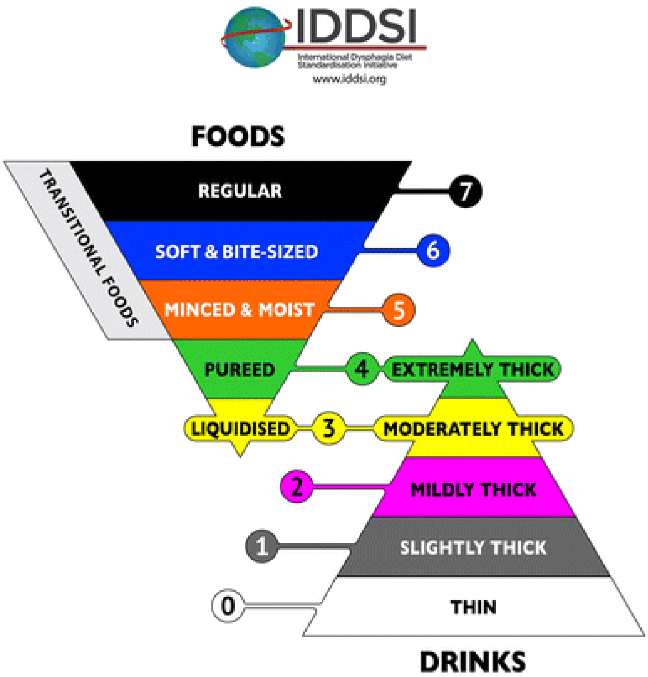

Figure 1. IDDSI framework graphic

Surface tension measurement

Surface tension measurements of thickened water and lemonade were made using a Du Nouy ring tensiometer (BZY-100, VTSYIQI, USA). To measure the surface tension, the Du Nouy ring calibrated with distilled water was placed under the surface of the liquid and the force required to separate the ring from the surface of the liquid was measured and converted to surface tension (σ). Measurements were made twice and the mean value was calculated.

Rheological analysis

A Brookfield viscometer (LVDV-E model; Brookfield Engineering Laboratories. Inc., Stoughton, MA, USA) was used to determine dynamic viscosity values. The rheological behavior of the prepared thickened water and lemonade was investigated by evaluating the viscosity (η) values against shear rate ($\dot{\gamma}$). The rheological data were adapted to Power Law and Herschel Bulkley models, which are frequently used in modeling flow behavior [18-19] Measurements were performed in triplicate using separate samples each time, and all experiments were performed at 25 °C.

Statistical test

For the comparison of the viscosity of the dispersion media, an analysis of variance was performed to determine statistical differences ($p < 0.05$). All statistical tests applied to perform nonlinear regression analysis on experimental viscosity data were performed using SPSS 22.0 for Windows (SPSS Inc., an IBM company, Chicago, IL, USA).

III. RESULTS AND DISCUSSION

Surface tension of thickened liquids

The surface tension of thickened liquids at IDDSI levels 1 to 3 is shown in Table 1. Complex dispersion media of fat and proteins inevitably inhibited the cohesive forces between water molecules, resulting in lower surface tension [20]. It is seen that the surface tension decreases with increasing thickener concentration. When the data are examined, it is seen that guar gum reduces the surface tension of water at 25 °C. There are not enough data points to conclude evaluating surface tension due to IDDSI consistency (only 3 concentrations).

The surface tension of guar gum-based solutions typically increased in acidic conditions due to the nature of the guar gum molecule and its behavior in different pH environments. Guar gum is a polysaccharide composed of mannose and galactose units. In an acidic environment, the protonation of some functional groups on the guar gum molecule can occur. This protonation can lead to changes in the molecular conformation, resulting in increased intermolecular interactions and higher surface tension [21].

Also, guar gum and pectin contain hydroxyl groups that can participate in hydrogen bonding. In acidic conditions, the protonation of functional groups can affect the availability and strength of hydrogen bond interactions, resulting in increased surface tension [22].

Flow curves of thickened liquids

Flow curves of apparent viscosity as a function of shear rate for samples of guar gum and pectin dissolved in different dispersion media at various concentrations according to IDDSI level are shown in Figure 2 and Figure 3, respectively. The apparent viscosity, which exhibits a tapering flow with shear stress, is inversely proportional to the shear rate [23]. The flow curves were obtained by fitting the experimental data (shear stress-shear rate) with the most commonly used Power Law and Herschel Bulkley models. These model equations are given below.

Power Law : $$\tau = \kappa.(\dot{\gamma})^n \quad (1)$$

Herschel Bulkley: $$\tau = \tau_0 + \kappa.\dot{\gamma}^n \quad (2)$$

Power law model was chosen as the appropriate model because it better represents the flow behavior of guar gum and pectin solutions compared to Herschel Bulkley model. The model coefficients and surface tensions of guar gum and pectin solutions in different dispersion media are given in Table 1 and Table 2.

These results may mean that there may be some interaction between guar gum and lemonade, that is, a change in the chain structure of guar gum when dissolved at low pH. A similar effect of the dispersion medium on the flow behavior has been demonstrated by previous studies [13-18].

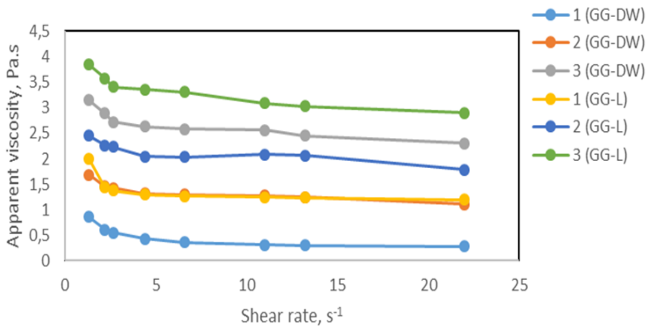

Figure 2. Typical flow curves for guar gum in different concentrations and dispersion media at 25°C

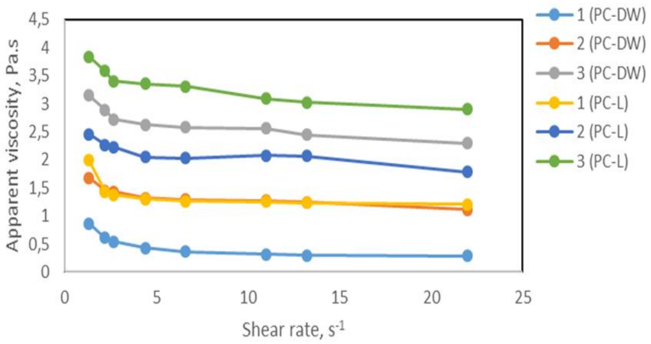

Figure 3. Typical flow curves for pectin in different concentrations and dispersion media at 25°C

Table 1. Surface tension values of thickened liquids prepared in different dispersion media

Thickener-dispersion medium	IDDSI	C (%w/v)	Surface Tension (mN/m)
Guar gum - deionized water	1	0.35	56.43±0.12
	2	0.45	55.84±0.21
	3	0.65	55.14±0.10
Guar gum-lemonade	1	0.35	65.20±0.13
	2	0.45	65.15±0.03
	3	0.65	64.33±0.15
Pectin-deionized water	1	3.30	48.03±0,09
	2	3.90	47.74±0,12
	3	4.50	45.12±0.10
Pectin-lemonade	1	3.30	59.15±0,40
	2	3.90	58.89±0,14
	3	4.50	57.09±0.11

Table 2. Power Law model parameters of thickened liquids prepared in different dispersion media

Thickener-dispersion medium	IDDSI	Power-Law Model		
		κ	n	R^2
Guar gum - deionized water	1	1.096	0.3079	0.9614
	2	2.374	0.2524	0.9965
	3	2.457	0.9638	0.9983
Guar gum-lemonade	1	1.628	0.3926	0.9550
	2	2.375	0.2626	0.9974
	3	2.450	0.9674	0.9988
Pectin-deionized water	1	1.831	0.1743	0.9761
	2	2.408	0.4987	0.9982
	3	2.477	1.132	0.9986
Pectin-lemonade	1	2.369	0.5426	0.9876
	2	2.490	0.8950	0.9979
	3	2.478	1.350	0.9996

Both guar gum and pectin can form gels in the presence of an acidic environment. In these conditions, the polysaccharide molecules can undergo a conformational change and interact with each other to form a gel network [24]. This gel structure contributes to significantly higher apparent viscosity.

Both guar gum and pectin typically exhibited shear thinning behavior, also known as pseudo-plasticity. This means that their apparent viscosity decreases with increasing shear rate or agitation. However, in an acidic environment, the shear thinning behavior of these polysaccharides may be altered. The extent and extent of shear thinning were affected by the acid level, resulting in a different apparent viscosity profile [25,26].

IV. CONCLUSIONS

In this study, the effects of dispersion medium (water and lemonade) on the surface tension and rheology of thickened liquids prepared with pectin or guar gum-based thickening powders were investigated. Following the well-defined power law relationship for the studied concentration range of dispersion media, deionized water, and lemonade, the apparent viscosity increased with increasing thickening powder concentration, while the surface tension decreased.

Guar gum and pectin are hydrocolloids that interact with water molecules in the surrounding medium. In an acidic environment, the protonation of functional groups on the polysaccharide molecules occurs. This protonation can enhance the interaction between the hydrophilic groups of the polymers and water molecules, leading to increased hydration and subsequent swelling of the polymers. This increased polymer-solvent interaction contributes to an increase in apparent viscosity.

As a result, Guar gum and pectin thickeners allow the liquid consistency to be adjusted to meet individual needs. Different thickening levels can be achieved by varying the concentration of thickeners, providing options for thin, nectar-like, honey-like, or pudding-like consistencies. This customization allows dysphagia patients to safely and comfortably swallow fluids of various tissues and pH.

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