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Research Article

Variation of Viscosities of Solutions Obtained from Apricot Powder at Different Temperatures and Concentrations with Shear Rate

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

[1]Fırat University, Faculty of Engineering, Department of Chemical Engineering, Elazığ, Türkiye, (ORCID: 0000-0001-5803-6821), mkozturk@firat.edu.tr
[1*]Fırat University, Faculty of Engineering, Department of Chemical Engineering, Elazığ, Türkiye, (ORCID: 0000-0002-1643-2487), ercanaydogmus@firat.edu.tr

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Abstract

Apricot, which is turned into powder without adding chemicals, and without spoiling its nature and nutritional value, can be used in bakery products, dairy products, and baby food. The shelf life of the apricot is extended by drying, grinding, and packaging. These powders can be easily dissolved in solvents such as water and are preferred as reinforcement material in the sectors. In this study, the rheological properties of apricot powder have been investigated. The change of viscosities of apricot powder prepared at different concentrations and shear rates has been observed. It is seen that the viscosity increases as the concentration of apricot powders raise. The temperature increase in the resulting mixture decreases the viscosity. In rheological studies, it has been determined that as the shear rate of the fluid increases, its viscosity decreases. It is seen that the solution (fluid) produced with apricot powders exhibits shear thinning behavior (pseudoplastic). The correlation coefficients are calculated by modeling the data obtained in experimental studies. It has been found that the experimental data with power-law model, among the models developed for non-Newtonian fluids in the literature, have the highest R^2 value.

Keywords: Apricot powders, rheological properties, shear thinning, pseudoplastic.

Kayısı Tozundan Elde Edilen Çözeltilerin Farklı Sıcaklık ve Konsantrasyonlardaki Viskozitelerinin Kayma Hızıyla Değişimi

Öz

Kimyasal ilave edilmeden, doğallığı ve besin değeri bozulmadan toz haline getirilen kayısı, unlu mamüller, süt ürünleri ve bebek mamalarında kullanılabilmektedir. Kurutma, öğütme ve paketleme ile kayısının raf ömrü uzatılmaktadır. Bu tozlar su gibi solventlerde kolaylıkla çözünebilmekte ve sektörlerde takviye malzemesi olarak tercih edilmektedir. Bu çalışmada kayısı tozunun reolojik özellikleri incelenmiştir. Farklı derişimlerde ve kayma hızlarında hazırlanan kayısı tozlarının viskozitelerinin değişimi gözlemlenmiştir. Kayısı tozlarının konsantrasyonu arttıkça viskozitenin arttığı görülmektedir. Elde edilen karışımdaki sıcaklık artışı viskoziteyi azaltmaktadır. Reolojik çalışmalarda akışkanın kayma hızı arttıkça viskozitesinin düştüğü tespit edilmiştir. Kayısı tozları ile üretilen çözeltinin (akışkan) kayma incelmesi (pseudoplastik) davranışı gösterdiği görülmektedir. Deneysel çalışmalarda elde edilen veriler modellenerek korelasyon katsayıları hesaplanmıştır. Literatürde non-Newtonian akışkanlar için geliştirilen modellerden power-law modeli ile deneysel verilerin en yüksek R^2 değerine sahip olduğu görülmüştür.

Anahtar Kelimeler: Kayısı tozları, reolojik özellikler, kayma incelmesi, pseudoplastik.

1. Introduction

Apricot (*Prunus armeniaca L.*) is an important source of nutrition in terms of vitamins, minerals, bioactive phytochemicals, and sugar. Türkiye provides a significant percentage of apricot production in World (Akin et al., 2008; Bashir et al., 2021). Bioactive components of apricot show the ability to reduce chronic diseases and therefore have pharmacological importance due to their high antioxidant activity (Rahaman et al., 2020). Furthermore, apricot is a fruit that does not have a long storage life due to its rapid ripening process and it becomes imperative to find other possible means to extend its shelf life.

Fruit powders are widely preferred in food formulations due to their advantages such as long shelf life, the convenience of storage and packaging, and low transportation cost (Martinelli et al., 2007). Drying, which is one of the different preservation methods developed, is particularly suitable for yielding products rich in vitamins and minerals (Igual et al., 2012; Huang et al., 2019; Deng et al., 2022). Dried and powdered fruit may be of interest as an ingredient that can be used in formulated foods, as it will provide a stable, natural product (Telis-Romero et al., 2007).

Determining the flow behavior of fluid foods is essential for the design and selection of pumps, conveying systems, equipment, and calculation of power requirements. In industrial processes, it is important to know the temperature change of the viscosity of the product subjected to a series of shear rates for equipment design (Salehi, 2020). Newtonian behavior, the simplest linear relationship between shear stress and shear rate, is not observed in most liquid foods, including fruit and vegetable derivatives. Therefore, complex models such as Power-law, Bingham and Casson, and Herschel-Bulkey models have been developed to explain the flow behavior of these foods (Quek et al., 2013; Diamante and Umemoto, 2015). Some researchers combined the variation of the viscosity of liquids with temperature and concentration into a single equation (Kaya and Belibagli, 2002; Togrul and Arslan, 2004; Arslan et al., 2005).

Many studies in the literature examine the rheological properties of Newtonian and non-Newtonian fluids. Shear thinning and shear thickening behaviors of the prepared fluid can provide advantages according to the intended use (Akpolat et al., 2022; Kök et al., 2022). Especially in industrial applications, liquid mixtures, solutions, emulsions, and solutions are used in many sectors. The transport of the fluid and its industrial applications are put into use after their rheological properties have been determined (Yanen et al., 2020; Yanen et al., 2021; Yanen et al., 2023).

This study aimed to investigate the effect of temperature and concentration on the rheological properties and flow behavior of apricot powder solutions. The effect of concentration was determined through power-law model. Two different models were used to examine the effect of temperature and concentration together, and the model that provided the best fit among these models was revealed by statistical tests.

2. Materials and Methods

2.1 Materials

Dried apricots were obtained from a local market in Elazığ, Türkiye. Apricots were pulverized using an electric grinder and stored in polyethylene bags at room temperature until used.

2.2 Preparation of apricot powder solutions

Apricot powder was dissolved in water to obtain different concentrations (8, 12, 16, 20, 24 kg/m^3), mixed in a mechanical mixer for 1 hour, and the solution was filtered. Before the rheological measurements, the solution was kept at room temperature for 30 minutes.

2.3 Measurement of viscosity

Prepared apricot powder solutions were subjected to a rotational viscometer (LVDV-E, Brookfield Engineering Laboratories, Inc., Middleboro, MA). The viscosities of apricot powder solutions prepared at different concentrations were measured using a Brookfield viscometer (LVDV-E, Brookfield Engineering Laboratories, Inc., Middleboro, MA) at different temperatures (20, 30, 40, 50, and 60 °C). Flow measurement was performed from a shear rate of 1.32 s^{-1} to a shear rate of 13.2 s^{-1} using the spindle LV-1 (Karataş et al., 2022).

2.4 Data analysis and mathematical modeling

Statistical software package (Statistica for Windows 5.0, 1995) was used to perform nonlinear regression analysis of experimental viscosity data. The determination coefficient (R^2), the average residuals (eave), and the mean relative percentage deviation modulus (E) were calculated using Microsoft Excel 2016 (XP Edition, Microsoft Corporation, USA):

$$\boldsymbol{E = \frac{100}{N}\sum_{i=1}^{N}\frac{|X_e - X_c|}{X_e}} \qquad (1)$$

$$\boldsymbol{e_{ave} = \sum_{i=1}^{N}\frac{(X_e - X_c)}{N}} \qquad (2)$$

3. Results and Discussion

3.1 Rheological behavior of apricot powder solutions

Shear stress (τ) was measured as a function of shear rate ($\dot{\gamma}$) in flow curve measurements. The apparent viscosity values as a function of shear rate and varying concentrations (8-24 kg/m^3) are shown in Figure 1-5 for varying temperatures (20-60 °C). As the shear rate increases, the interconnection of the chains decreases, so the apparent viscosity decreases and shear thinning properties occur. The apparent viscosities of the solutions decreased with increasing temperature and this may be caused by the branched structure of the polysaccharides in apricot powder (Xu et al., 2019; Zamani and Razavi, 2021). 3D surface plot of the apparent viscosity of apricot powder solutions is shown in Figure 6.

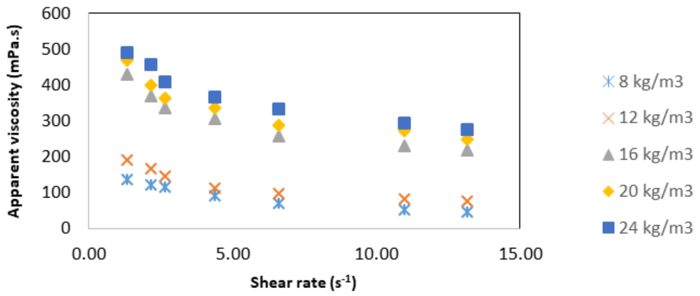

Figure 1. The influence of concentration on the apparent viscosity of apricot powder at 20 °C

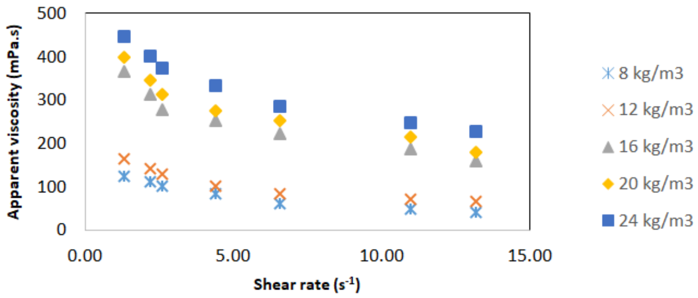

Figure 2. The influence of concentration on the apparent viscosity of apricot powder at 30 °C

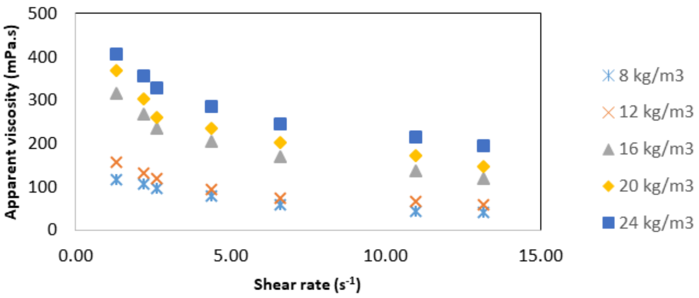

Figure 3. The influence of concentration on the apparent viscosity of apricot powder at 40 °C

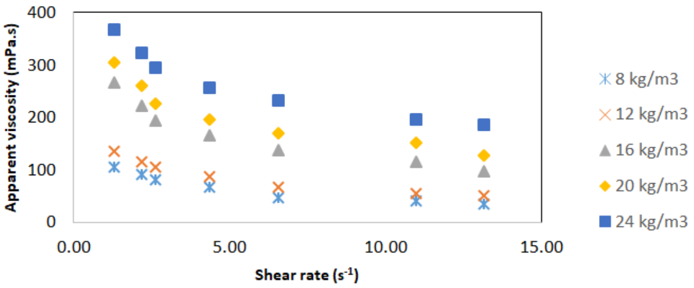

Figure 4. The influence of concentration on the apparent viscosity of apricot powder at 50 °C

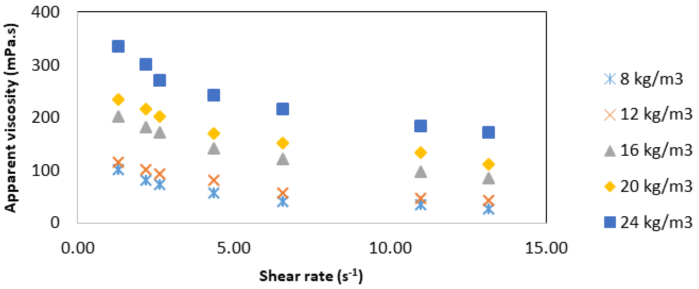

Figure 5. The influence of concentration on the apparent viscosity of apricot powder at 60 °C

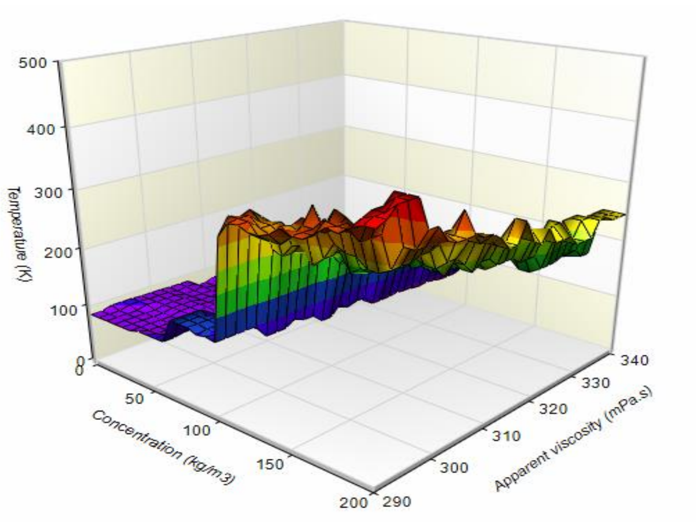

Figure 6. 3D surface plot of the apparent viscosity of apricot powder solutions

The variation of shear rate and shear stress for different concentrations of apricot powder solutions at 20 °C is given in Figure 7. Similar graphs were obtained for other temperatures (graphs not shown).

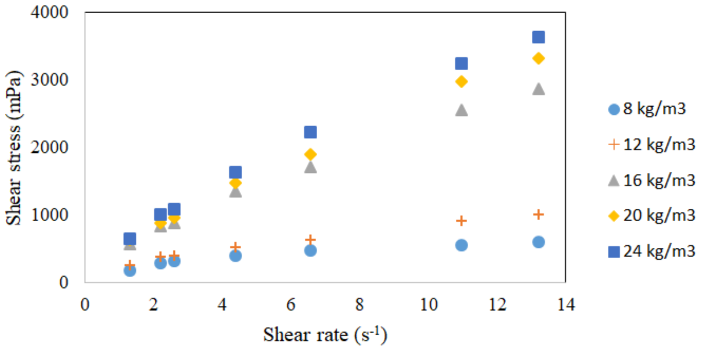

Figure 7. The plot of shear rate and shear stress for different concentrations of apricot powder solutions at 20 °C

The rheological data of the obtained apricot powder solutions were adapted to power-law rheological model given in Equation 3 (Corrêa et al., 2014).

$$\tau = \kappa.(\dot{\gamma})^{n} \qquad (3)$$

where κ is the consistency index and n is the flow behavior index (dimensionless). In power-law model, the constants k and n are required to characterize the flow behavior. It was found that power-law model fitted well with the experimental shear stress data as a function of the shear rate at different concentrations and temperatures. The flow behavior index found by applying power-law model ranged from 0.4222 to 0.7446 at varying temperatures and concentrations. When n is less than 1, which determines the type of fluid, the fluid exhibits pseudoplastic behavior (Krokida et al., 2001). Figure 8 shows that the consistency coefficient of apricot powder solutions decreases as temperatures increase and concentrations decrease.

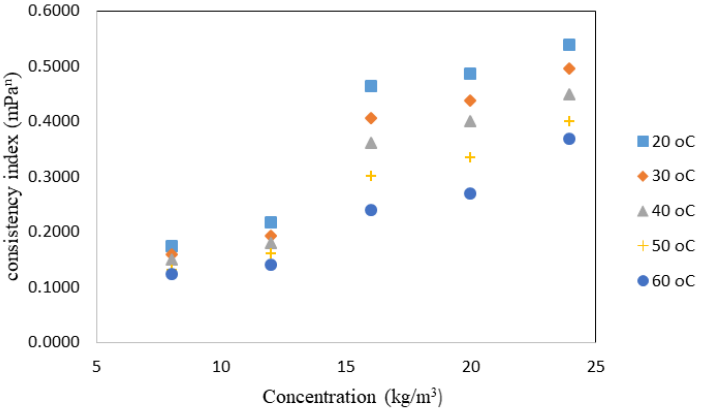

Figure 8. Consistency index as a function of the concentration of apricot powder solutions

The combined effect of temperature and concentration on the apparent viscosity of apricot powder solutions is explained by the two models given in Equation 4 and Equation 5:

$$\eta_a = \delta(C)^{\varepsilon}\exp(E_a/RT) \quad (4)$$

$$\eta_a = \delta_1\exp(\varepsilon_1 C)\exp(E_a/RT) \quad (5)$$

Equation coefficients were found by performing a nonlinear regression analysis of the experimental data, and the agreement between the calculated experimental data using these coefficients and the experimental data was revealed using statistical tests. Equation coefficients and statistical test results are given in Tables 1 and 2.

Table 1. The combined effect of temperature and concentration on apparent viscosity of apricot powder solutions (Equation 4)

Shear rate (s^{-1})	**$\eta_a = \delta(C)^{\varepsilon}\exp(E_a/RT)$**					
	δ	**ε**	**E_a**	**R^2**	**e_{ave}**	**E**
1.32	0.0860	0.8411	10.45	0.9298	0.6454	11.94
2.20	0.0559	0.8759	10.76	0.9476	0.2294	10.86
2.64	0.0501	0.8788	10.74	0.9503	0.0697	11.03
4.40	0.0220	0.8452	11.66	0.9377	0.1760	12.57
6.60	0.0105	1.047	11.89	0.9450	0.5375	13.51
11.00	0.0047	1.087	13.04	0.9460	0.6767	12.77
13.20	0.0025	1.122	13.94	0.9475	0.5335	12.12

Statistical analysis, when the R^2, e_{ave}, and E values were evaluated in fitting the apparent viscosity data as a function of temperature and concentration, it was observed that Equation 4 fitted much better than Equation 5. According to this equation, the activation energy was found to vary in the range of 10.45-13.94 kJ/mol. The activation energy found showed that the solutions were sensitive to temperature change at low shear rates.

Table 2. The combined effect of temperature and concentration on apparent viscosity of apricot powder solutions (Equation 5)

Shear rate (s^{-1})	**$\eta_a = \delta_1 \exp(\varepsilon_1 C) \exp(Ea/RT)$**					
	δ_1	**ε_1**	**Ea**	**R^2**	**e_{ave}**	**E**
1.32	2.337	0.0068	10.0	0.8742	2.435	17.01
2.20	1.954	0.0071	10.0	0.9038	2.215	15.28
2.64	1.750	0.0071	10.0	0.9138	1.857	13.93
4.40	1.438	0.0076	10.0	0.8923	2.384	17.05
6.60	1.117	0.0082	10.0	0.8964	2.696	20.99
11.00	0.930	0.0085	10.0	0.8855	2.976	22.80
13.20	0.799	0.0088	10.0	0.8908	2.966	22.23

4. Conclusions

The apparent viscosity of apricot powder solutions increased with increasing concentration and decreased with temperature. These solutions exhibited pseudoplastic rheological behavior (shear thinning) well defined by the force law model with a flow behavior index of less than 1. While consistency index values increased with concentration, an inverse trend was observed with temperature. To estimate the apparent viscosity of apricot powder solutions, the exponential models for concentration and Arrhenius relationship for temperature were combined to express the combined effect of concentration and temperature. The model with the best performance can be applied to predict the apparent viscosity of apricot powder solutions.

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