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EFFECT OF TEMPERATURE AND CONCENTRATION ON THE RHEOLOGICAL PROPERTIES OF FIG JAM PUREE

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ABSTRACT

The rheological properties of Fig jam puree were studied at the range 40-65 % solid concentration of Fig jam puree within temperature range 20-90°C and spindle speed of 10-50 rpm. Dependence of apparent viscosity on temperature was related through the Arrhenius law. The plot of lnμ versus 1/T exhibits three regions with different temperature dependencies at concentration 65%, a reasonable explanation was presented for this phenomenon. Also, this study includes the dependence of the apparent viscosity of Fig jam puree on solid concentration that follows the power law relationship. An interpretation of the relation between the constants of the power law and shear rate was deducted.

KEYWORDS

Activation energy, effect of temperature , Rheology of jams, Effect of concentrations.

NOMENCLATURE

A	Constant in Arrhenius law.
C	Concentration, wt%.
E_a	Activation energy, J/gmole.K.
k	Empirical constant.
R	Gas constant, 8.314 J/gmole.
T	Temperature, K.
μ_1 and α	Empirical constants related to shear rate.
μ	Viscosity, Pa.sec.
γ	Shear rate, sec^{-1}.

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1 INTRODUCTION

Rheological properties of food materials are valuable and useful in their processing, handling and storage. The flow properties of fruits and vegetables are essential for the design and evaluation of food equipments. Several studies have been conducted on the rheological properties of fruit purees and juice. Vitali and Rao [1] obtained rheological data on low pulp concentrated orange juice sample as a function of temperature, Speers and Tung [2] studied the apparent viscosities of xanthan gum dispersions over shear rates of 0.5-3000 s^{-1} at concentrations of 0.05-1.00% (w/w) and temperatures of 5 - 45°C. A combined model equation was derived to describe the variation of viscosity with shear rate, concentration and temperature for aqueous dispersion of xanthan gum.

$$\mu = 396\, \gamma^{-0.642}\, C^{1.22}\, e^{668/T} \quad (1)$$

Where, μ is the viscosity, Pa.s, γ is the shear rate, sec^{-1}, C is the concentration, % (w/w) and T is the temperature in K.

Velez-Ruiz and Barbosa-Canovas [3] evaluated the flow properties of concentrated milk at concentrations between 12.6 and 48.6 % solids content, at three temperatures and through 4 weeks of storage. Three rheological models, Newton, power law and Herschel-Bulkley law, were applied to fit the flow behavior of milk concentrates depending on concentration level. The effect of temperatures studied on the flow behavior index was minimal, though noticeable on the consistency coefficient, and at the three selected temperatures (5, 15 and 25°C) the flow behavior index decreased with storage time while the consistency coefficient increased. The energy of activation for flow increased with concentration and storage time and ranged from 2.42 to 11.8 kcal/gmol. The same findings concerning consistency coefficient as a function of temperature were obtained by Nindo et al. [4].

Bhandari, et al. [5] studied the effect of temperature on the viscosity of seven varieties of commercial Australian honeys. These followed an Arrhenius type relationship, and the activation energy ranged from about 1250 to 1850 J/gmole and was also found to depend of the type of honey. The same conclusion was reached previously by Junzheng [6] and later by Sopade et al. [7] upon investigating the rheological behavior of several types of honey.

Cepeda and Villaren [8] studied the influence of temperature on the rheological behavior of depectinised juice of Malus floribunda. The variation of viscosity with temperature followed the Arrhenius- Guzman equation with activation energy values between 26.6 and 64.8 kJ/gmole.

Grigelmo et al. [9] determined the flow behavior of peach, dietary fibre (DF) suspensions with a concentric cylinder viscometer at a temperature range of 15-65°C. The Arrhenius model equation described the effect of temperature on the apparent viscosity (η_{app}) and the activation energy of flow (E_a) was in the range 5.2-14.3 kJ/mole, depending on the concentration. Changes of the apparent viscosity with concentration in pseudoplastic suspensions fitted well to a power law model equation at the used temperature range. On the other hand, Mukprasirt, et al. [10] showed that the relationship between the apparent viscosity of rice flour-based batter and temperature can be predicted within a shear rate range between 30 to 132 sec^{-1}

at which the batter behaved more like a Newtonian fluid, they obtained the following equation:

$$\mu_{app} = k_t \exp (E_a/RT) (\gamma)^{n-1} \quad (2)$$

Where, μ_{app} is the apparent viscosity, Pa.s, k_t is an empirical constant, γ is the shear rate, sec^{-1}, E_a is the activation energy, J/gmole, R is the gas constant, 8.314 J/gmole, and n is the flow behavior index.

Altay and Ak [11] showed that the steady shear behavior of Tahin was pseudoplastic at temperatures between 20-70°C and shear rates in the range of 0.13-500 sec^{-1}. The consistency coefficient exhibited strong temperature dependence for which the activation energy of flow was 21.6 kJ/mole.

The variation of viscocity with temperature followed Arrhenius equation in a study on baker's yeast suspensions by Mancini and Moresi [12] and a study on commercial Mustards by Juszczak et al [13].

In this paper the rheological properties of Fig jam puree were studied at the range 40-65 % (wt. %) solid concentration of Fig jam puree within temperature range 20-90°C and shear rate of 2.2-11 sec^{-1} corresponding to spindle speed of 10-50 rpm.

2 EXPERIMENTAL PROCEDURES

2.1 Materials and Methods

Six samples of Fig Jam puree with different solid concentrations (40, 45, 50, 55, 60, 65% wt%) were taken during the processing of the jam.

Fig puree jam is obtained from fresh Fig fruits which have been cleaned by a special washer then passed to a refiner which separates the pulp from fiber, the pulp is then packed in a container.

The fig puree is then manufactured using the following procedure:-

1- The fig puree is transferred to a vacuum pan with suction and, if needed, a little treated water is added to rinse out the last of the material.

2- Addition of sugar to the pulp with weight ratio 1:1 fig pulp to sugar, and citric acid 2.6gm per kilogram pulp.

3- The vacuum pan is heated to 80-90°C with stirring until the puree reaches about 65% concentration.

4- The puree jam is then pumped to the filler where it is packed.

2.2 Rheological properties:

Flow properties (shear stress, shear rate, and apparent viscosity) of Fig jam puree were measured directly with Brookfield Digital Rheometer, Model DV-III (Brookfield Engineering Laboratories INC). The puree was placed in a small sample adapter; the SC4-25 spindle was selected for the sample measurement. A thermostatic water bath provided with the instrument was used to regulate the sample temperature. The rheological parameters for Fig jam puree were studied in the temperature range of

20-90°C and spindle speed between 10-50 rpm at concentrations of Fig jam puree in the range 45-65% (measured using an Abbe type Refractometer).

3. RESULTS AND DISCUSSION

A previous study on Fig Jam puree conducted by the same authors [14] indicated that the puree behaves as a Non-Newtonian Bingham plastic fluid with yield stress.

3.1 Effect of Temperature:

Figures 1-6 show the variation of viscosity with temperatures (20,40, 50, 60, 70, 80, 90°C) at different shear rates (2.2, 3.3, 4.4, 5.5, 6.6, 7.7, 8.8, 9.9, 11 sec^{-1}) and different concentrations (40,45, 50, 55, 60, 65%). Also, fluctuations in viscosity at certain temperature range appear. These fluctuations [Fig. 2] may be explained due to local agglomeration of the dispersed solid particles around the spindle, which leads to a fictitious increase in viscosity, at higher rpm, this effect disappears. Also, in Fig. 3 the dispersed phase is more uniformly distributed such that the previously described phenomenon does not show up.

It is clear from these figures that the viscosity decreases with increasing temperature at any shear rate. On the other hand, it is noticed that the fluctuations in viscosity decrease with higher concentration (60-65%) where the curves tend to be smooth and parallel to each other. This may be explained by the fact that pectin set is completely formed at concentrations (60-65%), Imeson [15].

As reported by several authors [Ahmed, J., et al. [16], Mancini and Moresi [12], Juszczak et al. [13]] the relation between viscosity and temperature for liquids usually follows Arrhenius equation:

$$\mu = A\, e^{-Ea/RT} \qquad (3)$$

Where, E_a is the activation energy, kJ/kg mole, A is a constant, R is the gas constant, 8.314 J/gmole, and T is the temperature, K

Hence, a plot of ln μ against 1/T should give a straight line from which the activation energy can be calculated. This plot was made for concentration 65% at different shear rates [Table 1].

A plot of ln μ versus 1/T exhibits three regions with different temperature dependencies. The existence of these regions is due to the change in activation energy values of the sample, as shown in Table 1 and Figures 7-9. The values of activation energy in the middle region (40-60°C) is almost constant, this may be referred to the contradiction between two factors affecting viscosity, one of them is the decrease in viscosity due to increase in temperature, the other one is the increase in viscosity due to pectin set formation. This contradiction results in a region of constant activation energy.

The existence of more than one region in viscosity dependence on temperature was previously noticed in the work of Afonse, et al. [17] on stirred yoghurt. The authors studied that the existence of two regions with different temperature dependencies is evident from the changes in the activation energy values of the samples. For temperatures below 25°C, all samples showed activation energy values rather lower than those for temperatures above 25°C. They thought that the reasons for this behavior are probably related with the restart of the bacteria activity.

It was, however, possible to correlate viscosity to temperature and shear rate, over the whole concentration range (40-65% wt).

The general Equation (4) takes the form:

$$\ln\mu = 0.12\times10^{11}(1/T - 0.003)^3 - 0.13\gamma + 2.286 \quad (4)$$

This equation was found to fit remarkably with a maximum error of 6%.

3.2 Effect of Concentration:

The effect of concentration on the apparent viscosity of Fig jam puree at shear rate values between 2.2-11 sec^{-1} were investigated over a temperature range 20-90°C.

Figure 10 describes the variation of viscosity with concentration at shear rate 11sec^{-1}. The same trend was observed in the remaining applied shear rates. This change follows a power law relationship shown in Equation (5), which was mentioned in the work of Grigelmo et al. [9] on peach dietary fiber suspension.

$$\mu = \mu_1 C^{\alpha} \quad (5)$$

where, μ is the viscosity, Pa.s, C is the concentration, wt%, μ_1 and α are empirical constants related to shear rate.
The values of α at each shear rate were found to be constant over the temperature range investigated. The value of α decreases, however, as the shear rate is increased. The following simple linear relation was obtained between α and γ :

$$\alpha = 5.5 - 1.2\,\gamma \quad (6)$$

The decrease in value of α with increasing shear rate means that, as the shear rate increases, (which in practice means an increase in agitation rate), the dependence of viscosity on concentration decreases.

The values of μ_1, however, do not follow a regular pattern with an increase in temperature. However, at fixed temperature, the values of μ_1 tend to increase with increased shear rate, particularly at high temperatures, μ_1 is a measure of sensitivity of viscosity to shear rate.

4 CONCLUSION

This study shows the effect of temperature on the apparent viscosity of Fig jam puree. The apparent viscosity decreases as temperature increases and follows Arrhenius model that exhibits three regions with different temperature dependencies, this is referred to the contradiction between two factors affecting viscosity, the decrease in viscosity due to the increase in temperature and the increase in viscosity due to the pectin set formation. The effect of concentration on the apparent viscosity of Fig jam puree followed the power law model. It was possible to correlate viscosity to temperature and shear rates over the whole range of concentration using data analysis programmer.

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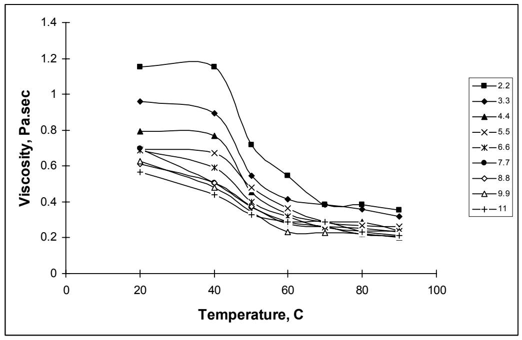

Fig. 1 Relation between viscosity and temperature at 40% solid concentration of Fig jam puree and at different shear rates.

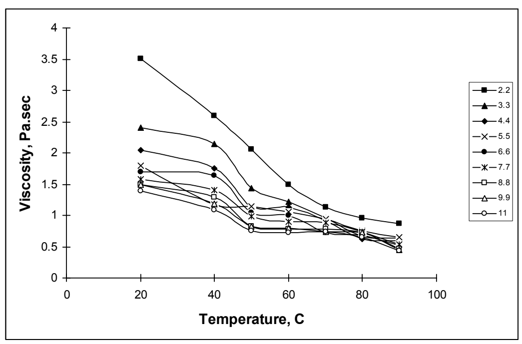

Fig. 2 Relation between viscosity and temperature at 45% solid concentration of Fig jam puree and at different shear rates.

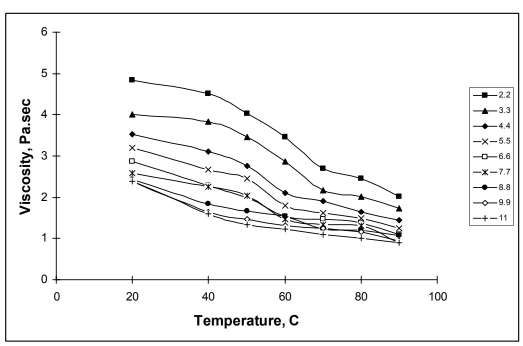

Fig. 3 Relation between viscosity and temperature at 50% solid concentration of Fig jam puree and at different shear rates.

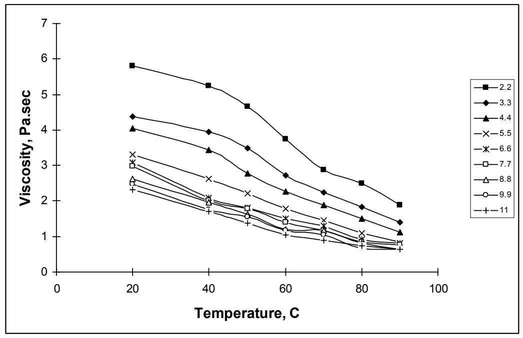

Fig. 4 Relation between viscosity and temperature at 55% solid concentration of Fig jam puree and at different shear rates.

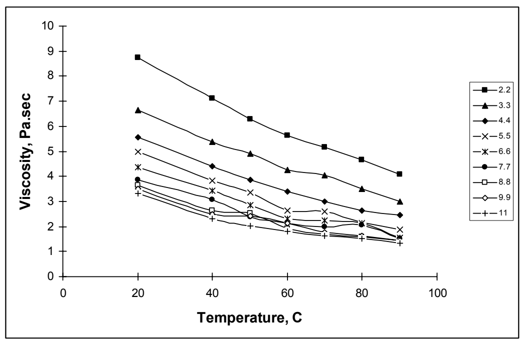

Fig. 5 Relation between viscosity and temperature at 60% solid concentration of Fig jam puree and at different shear rates.

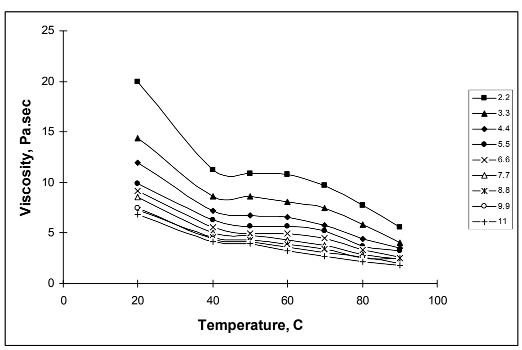

Fig. 6 Relation between viscosity and temperature at 65% solid concentration of Fig jam puree and at different shear rates.

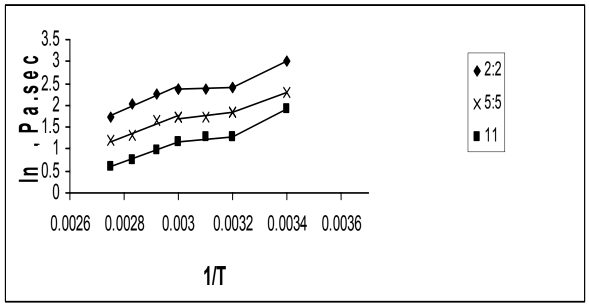

Fig. 7 Activation energy at different temperatures and shear rates.

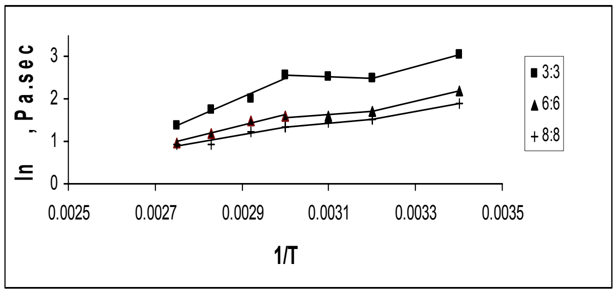

Fig. 8 Activation energy at different temperatures and shear rates.

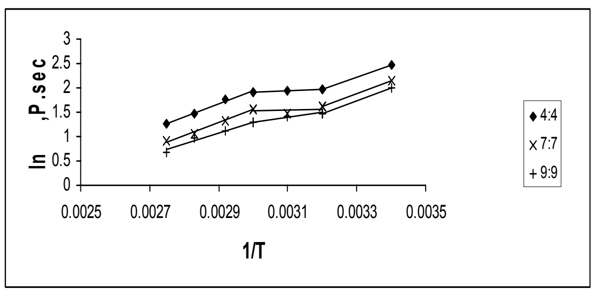

Fig. 9 Activation energy at different temperatures and shear rates.

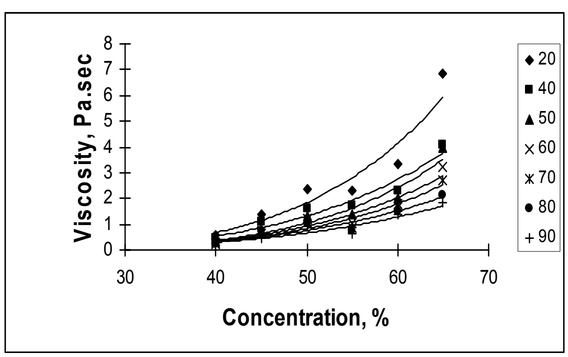

Fig. 10 Effect of concentration on viscosity at different temperatures, at shear rate=11sec^{-1}

Table1. Activation energy at different shear rates and temperatures

shear rate, sec^{-1}	Temperature, ^{o} C	activation energy, kJ/kgmole
2.2	60-90°C 40-60°C 20-40°C	21979.7 1603.94 21882.45
3.3	60-90°C 40-60°C 20-40°C	25268.74 1607.84 19366.632
4.4	60-90°C 40-60°C 20-40°C	22105.263 2823.0187 19557.022
5.5	60-90°C 40-60°C 20-40°C	19645.982 5053.25 16896.542
6.6	60-90°C 40-60°C 20-40°C	21234.78 5280.7 18985.85
7.7	60-90°C 40-60°C 20-40°C	22347.2 2470.84 19976.879
8.8	60-90°C 40-60°C 20-40°C	19902.885 6682.87 20071.66
9.9	60-90°C 40-60°C 20-40°C	19482.196 8531.827 20071.66
11	60-90°C 40-60°C 20-40°C	18965.897 10746.676 19519.61