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EFFECT OF TEMPERATURE ON FLOW BEHAVIOR DURING EVAPORATION PROCESS OF POMEGRANATE CONCENTRATE (DIBS)

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ABSTRACT

Flow behavior of pomegranate juice concentration during evaporation process was studied at different solid concentrations (23, 30, 40, 50, 60 and 70%), different temperatures (30, 40, 50, 60 and 70°C) and different shear rates ranged from 9.30 to 39s^{-1}. Pomegranate juice concentrate exhibited non-Newtonian pseudoplastic behavior. Consistency index increased with increasing concentration of pomegranate juice. The effect of temperature on apparent viscosity was described by Arrhenius law, the activation energy was ranged from 14.23 to 57.55 kJ/mol.K, Two models were used to describe the effect of concentration on activation energy and the effect of concentration on consistency index.

***Keywords*: Activation Energy, Dibs, Flow Behavior, Pomegranate Concentration, Shear Rate**

I. INTRODUCTION

Pomegranate is consumed both as fresh fruit and fruit juice. It is also being used in the production of jam, wine, liqueur, food coloring agent and flavor enhancer. The kernels are also used as a garnish for desserts and salads [1].The pomegranate molasses is commonly used in salads and many dishes in Turkey [2]; [3].

Pomegranate is a rich source of anthocyanins, ellagitannins and other phenolic compounds which are already proved to have antioxidant and antimicrobial activity [4]. Major hydrolysable tannins in pomegranates are gallotannins, ellagic acid tannins and gallagyl tannins (these are termed as "punicalagin"s). These compounds are found abundantly in the pomegranate juice (< 2g/L). It is also stated that punicalagins have the highest antioxidant activity. The antioxidant level in pomegranate juice was higher than found in other fruit juices, e.g. blueberry, orange, and red wine. Recently, the bioavailability of these compounds has been studied in vitro and in vivo analyses. Pomegranate juice has also important clinical implications, and it has been recommended in the treatment of AIDS [4]. Researchers found that daily consumption of pomegranate juice may improve stress-induced myocardial ischemia in patients who have coronary heart disease and they also reported that the pomegranate juice not only prevented hardening of the arteries by reducing blood vessel damage, but also reversed the progression of this disease [5]. Kernels of pomegranate are good source of phyto-estrogens. By strong antioxidant and anti-inflammatory effects pomegranate juice suppresses cancer activity.

As every fruit juice is composed of soluble solids in an aqueous phase, its rheological behavior will be influenced by the concentration and chemical composition of the solids. Heating processes significantly change the thermo-physical properties of fruit juices. It is necessary to study thermodynamic and transfer properties of fruit juices, particularly viscosity in order to understand and control the juice production processes. Knowledge of the viscosity has great importance in fruit juice industry. Since the fruit juices are subjected to different temperatures and concentrations during processing, storage, transport, marketing and consumption, the viscosity is studied as a function of temperature and concentration [6].

Rheological measurements are quite relevant in the food industry as a tool for physical characterization of raw material prior to processing, for intermediate products during manufacturing and for finished foods [7]. The processing of commercialised juice is subjected to tight supervision because its properties, such as viscosity, concentration and temperature vary during processing [8]. The knowledge of rheological behavior of fruit juices and concentrates is useful in quality control, sensory evaluation and engineering applications while designing industrial plants [9] and also in determining the power requirements for pumping and sizing of pipes in its processing.

The rheological behavior of litchi juice concentrate prepared from two cultivars viz. cv. Dehradun and cv. Seedless late was studied as a function of storage temperature, storage period and preservative used during storage for six months. The rheological behavior of prepared juice concentrate was studied at temperature range of 20-50°C over the shear rate of 0.6-145.80 s^{-1} and the data was fitted to power law equation. The increase in viscosity was higher in the concentrate stored at low temperature as compared to the samples stored at ambient temperature in both varieties. The activation energy ranged between 29.38-44.27 kJ/mol and 28.88-42.45 kJ/mol for *cv. Dehradun* and *cv. Seedless late*, respectively [10].

Viscosity is an important factor during the concentration of juices, especially in the production of high density concentrates due to the inefficiency of the operation when the product becomes highly viscous [11]. Therefore, experimental measurements of viscosity are necessary for the characterization of fluid foods.

The objective of this study was investigate the effect of temperature on flow behavior of the pomegranate juice concentrate during evaporation process as well as modeling of its rheological data using flow equations for designing pomegranate concentration processes such as evaporation, pumping …….etc.

II. MATERIALS AND METHODS

2.1 Preparation of Pomegranate Concentration

Pomegranate fruits were supplied by a local Egyptian market. After washing and peeling, juice was extracted. The Pomegranate juice was concentrated to 70% using a rotary vacuum evaporator (Model R II, BuchiLaboratoriums- Technik, Flawil, Switzerland) at 60°C and immediately stored in refrigerator at 4°C till used. Samples with lower soluble solids (23, 30, 40, 50, 60 and 70%) were taken during evaporation process.

2.2. Rheological Measurements

The rheological behavior of Pomegranate juice samples with different concentrations (23, 30, 40, 50, 60 and 70 %) and temperatures (30, 40, 50, 60, and 70°C) was studied using a Brookfiled rotational viscometer (DV-III+, ultra, Brookfield Engineering Laboratories, Inc). Rotor speed was variable in the range 10–100 rpm. The viscometer temperature was controlled using a thermostatic circulating water bath.

III. RESULTS AND DISCUSSIONS

3.1. Shear rate – Shear stress relation

Fig.1 shows that the values of shear stress against shear rate for six solids concentrations (23, 30, 40, 50, 60, and 70%) and five degrees of temperatures (30, 40, 50, 60, and 70°C).

Figure 1 shows the shear rate shear stress data at different temperatures (30 - 70°C) and 70% solid concentration of pomegranate juice. The results observed that all samples exhibited Non-Newtonian pseudoplastic behavior at all temperature studied and fitted well to equation (1).

$$\tau = K\,\gamma^{n} \qquad (1)$$

Where, τ is shear stress (Pa), *K* is consistency index (Pa sn), γ is shear rate (s^{-1}), n is the dimensionless flow behavior index. The same trend was observed at different concentration of pomegranate juice (23 – 60%). Similar results have been also reported in other studies [12] and [13].

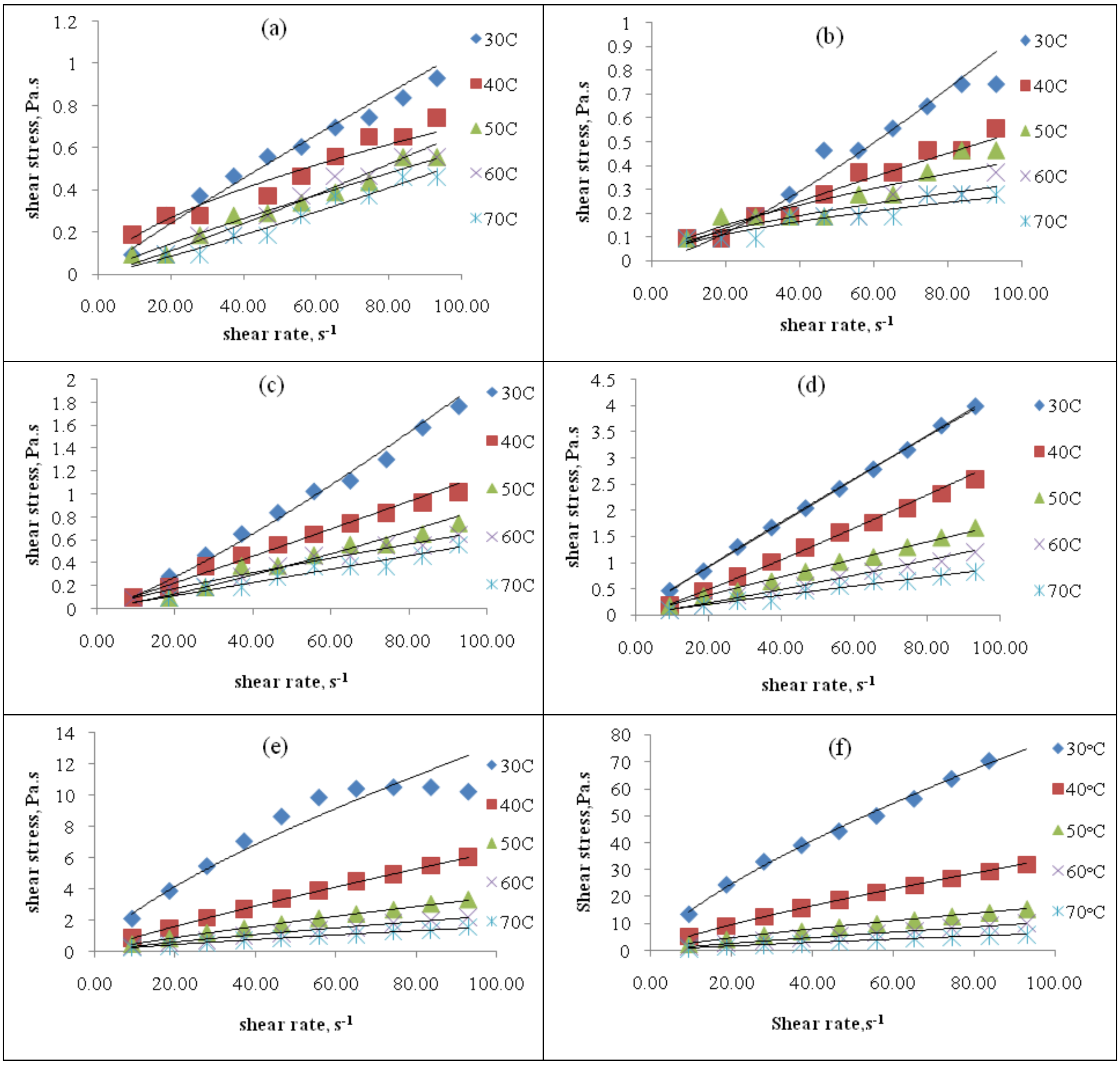


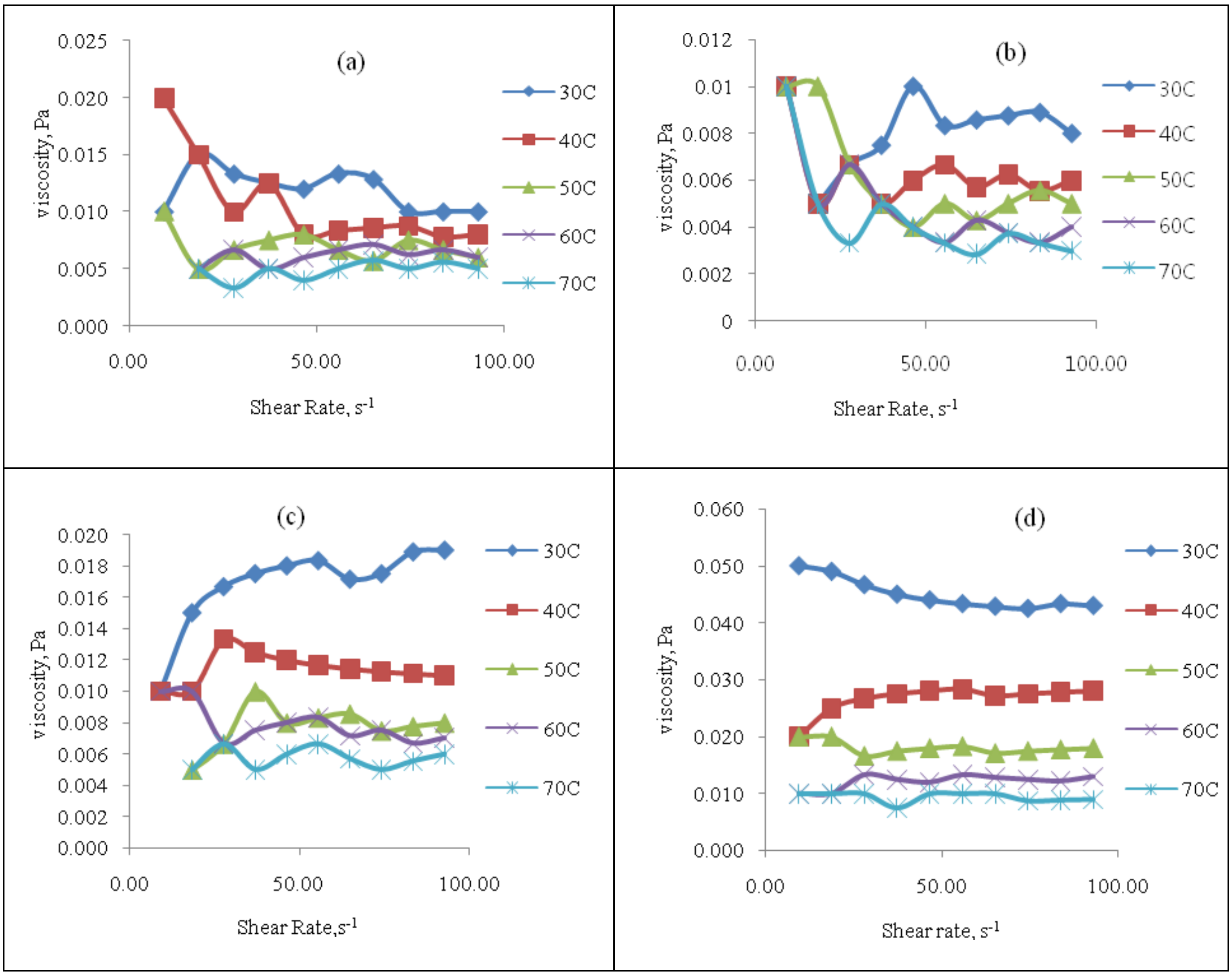
Figure1.Effect of Shear Rate on Shear Stress of Pomegranate Juice Concentrates at Different Temperatures. Pomegranate Concentration (A) 23%, (B) 30%, (C) 40%, (D) 50%, (E) 60%, (F) 70%

The pseudoplastic behavior of pomegranate juice concentrate can be attributed to discontinuous phase substances, such as fibrous materials, when water acts as a continuous phase. Insoluble solids consist mainly of pectic substances. According to [14], who studied that pectin is the major factor that increases the viscosity of a food product, whereas protein plays a minor role.

3.2. Effect of shear rate on apparent viscosity

Fig. 2 shows the effect of shear rate on apparent viscosity of pomegranate juice concentrate, the results observed that as shear rate increased the apparent viscosity decreased at all temperature and concentrations studied. Fig. 3 and 4 show Consistency index (k) increased with increasing concentration of pomegranate juice at all temperatures studied. Flow behavior index didn't give a good trend with increasing concentration at all temperatures studied.

[15] reported that the pectinacious substances possess a high water holding capacity and develop a cohesive network structure.The chemical characteristics, especially pectin content and sugar composition, and the processing procedures (such as finishing and clarification) for juices are likely factors that can explain the differences in rheological properties.



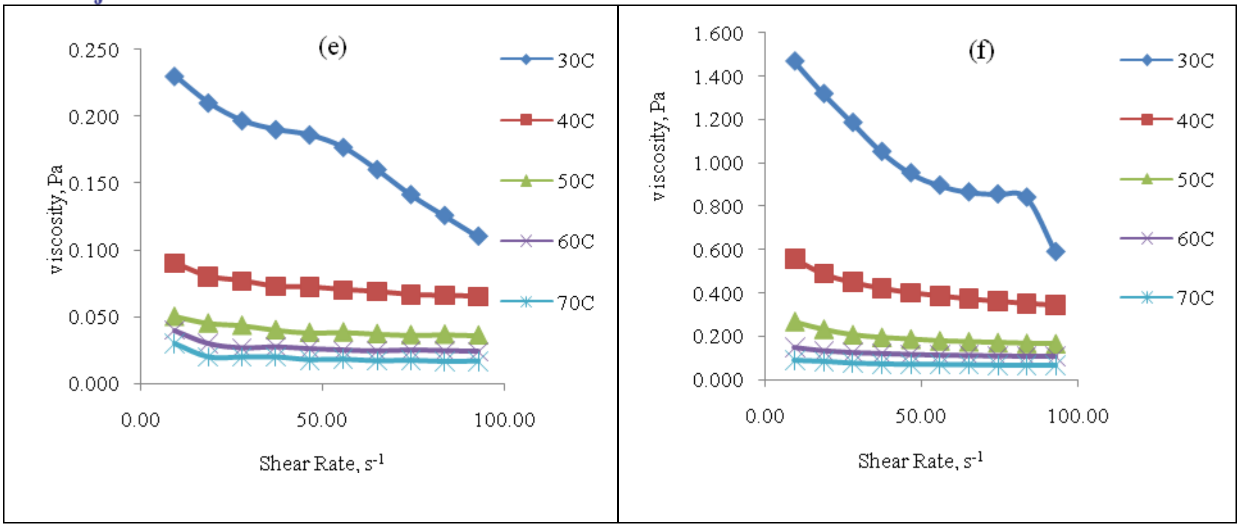


Figure2: Effect of shear rate on viscosity of pomegranate juice.
Pomegranate Concentration (a) 23%, (b) 30%, (c) 40%, (d) 50%, (e) 60%, (f) 70%

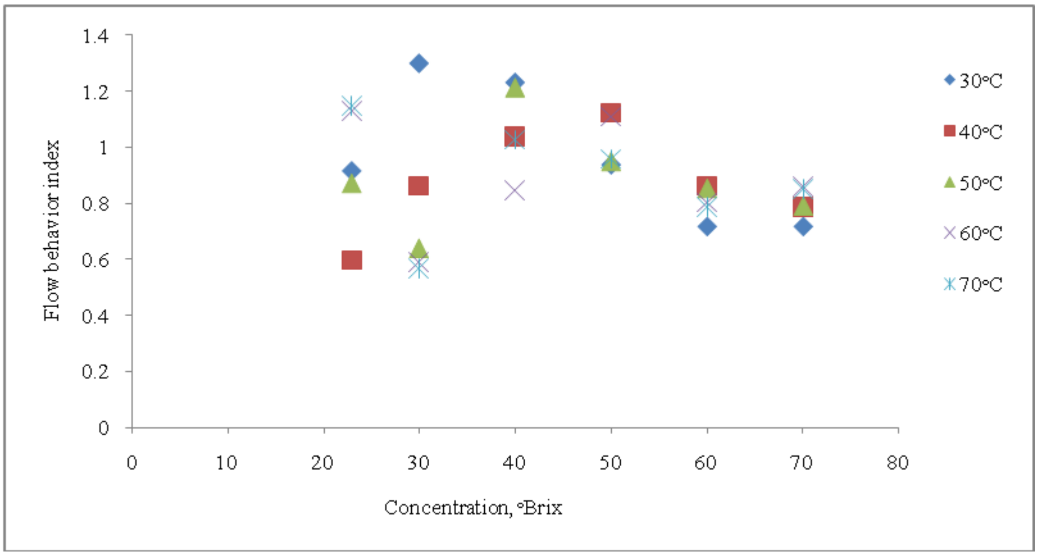


Figure.3. Effect of concentrations on flow behavior index at different temperatures

3.3. The effect of concentration on consistency coefficient

The effect of concentration on consistency coefficient could be described by either an exponential-type or a power type relationship. For a power-type relationship, the consistency coefficient varies with the concentration raised to a given power:

$$K= K_1C^{A1} \qquad (2)$$

For an exponential-type relationship, the function is exponential:

$$K=K_2\exp(A_2C) \qquad (3)$$

In both equations, K_1(Pa s), K_2(Pa s), A_1(dimensionless) and A_2(dimensionless) are constants and C is the concentration expressed as %. The experimental data were fitted to the linear form of Equations (3) and (4) by linear regression analysis to evaluate constants in Equations. Table (1) shows the parameters of the two equations at different temperatures. Based on the values of the $R^2$the exponential model fitted well to describe the effect of soluble solids on the consistency coefficient of pomegranate juice concentrations. It can be observed that *K1* decreased as the temperature increased. Also, it is obvious that with the increase in temperature from 30 to70°C, the concentration dependency of *K* decreased.

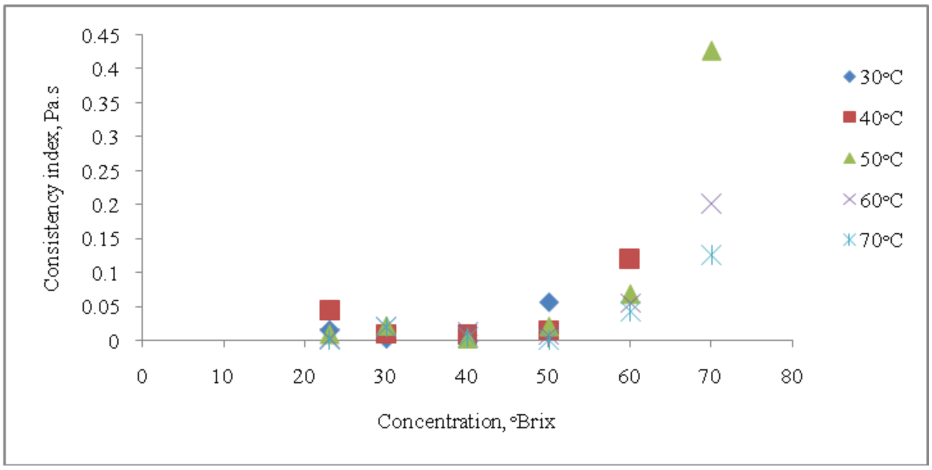


Figure4: Effect of concentrations on consistency index at different temperatures

Table1: The effect of concentration on consistency (K) at different temperatures.

Model	$K=K_1C^{A1}$			$K=K_2exp(A_2C)$		
T (°C)	R^2	A_2	K_2	R^2	A_1	K_1
30	0.993	0.187	5E-06	0.963	8.742	1E-16
40	0.952	0.158	1E-05	0.913	8.326	2E-16
50	0.992	0.16	5E-06	0.989	8.592	5E-17
60	0.865	0.085	1E-07	0.744	5.251	3E-18
70	0.910	0.237	1E-08	0.935	14.290	8E-28

3.4. Activation Energy

Fig.4 shows that viscosity decreased with an increase in temperature and a decrease in solids concentration. The effect of temperature on viscosity follows the Arrhenius-Guzman equation (Equation (2)) with R^2 values greater than 0.95. Magnitudes of activation energy for flow, relating the apparent viscosity to temperature, ranged from 14.23 to 57.55 kJ/molas shown in (Table 2).

The effect of temperature on μ was described by the Arrhenius- Guzman equation:

$$\mu = \mu_1 \exp\left(\frac{E_a}{RT}\right) \quad (4)$$

Where, μ_1 is the frequency factor (Pa s),

Ea is the activation energy (J/mol),

R is the universal gas constant (8.314 J/mol K),

T is the absolute temperature (K).

Activation energy is necessary to move a molecule, and as the temperature increases the liquid flows more easily due to higher activation energy at high concentrations.

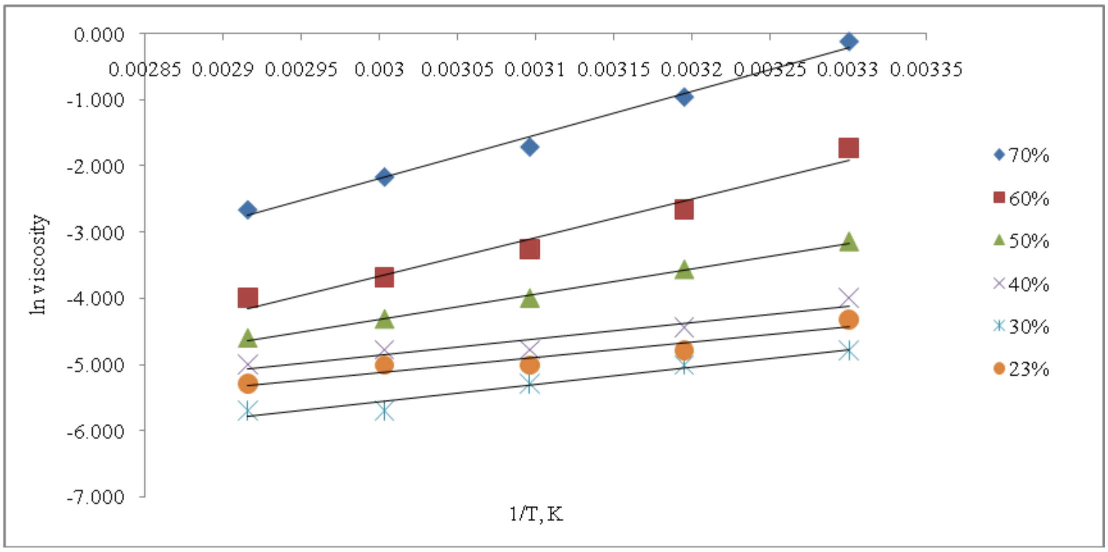


Figure.5. Effect of temperature on viscosity at shear rate 55.80 s^{-1}

Table2: The activation energy of pomegranate at different concentrations

Conc. %	Ea, kJ/mol K		
	9.30s^{-1}	55.80 s^{-1}	93.00 s^{-1}
23	33.32	18.61	14.23
30	36.74	20.14	19.99
40	43.59	21.42	23.55
50	43.59	31.23	32.96
60	48.35	47.34	40.10
70	57.55	53.58	47.03

The general tendency is for the activation energy to increase with the soluble solids concentration. In the present work, the value of *Ea*increased with concentration, the largest value of 57.55 kJ/mol corresponding to the highest concentration, 70% at 9.30 s^{-1}. This observation indicates that the effect of temperature in decreasing the viscosity of pomegranate juice concentrates is more pronounced at higher solids concentrations. [15] observed a similar trend for clarified apple and banana juices.

3.5. Effect of concentrations on activation energy

The effect of concentration on activation energy was studied by two models, power law and exponential models:

$$Ea= E_1C^{B1} \quad (5)$$

$$Ea= E_2\exp (B_2C) \quad (6)$$

Where, *C* is the concentration expressed as °% and E_1, E_2, $B_1$and $B_2$are constants. The values of *Ea*and their respective concentrations were fitted to Equations (5) and (6) by the least square methods to obtain the estimates of the parameters of the model. The parameters calculated for these models are given in Table (3). It was found that the exponential model was able to describe better the dependency of *Ea*on soluble solids content. Also, other studies showed that exponential model could describe dependency of *Ea*on soluble solids content in Gaziantep pekmez and tahinpekmez blends [13].

Table3: The effect of concentration on the activation energy flow

shear rate, s^{-1}	$Ea=E_1(C^{B1})$			$Ea=E_2 exp(B_2C)$		
	E_1	B_1	R^2	E_2	B_2	R^2
9.3	8.157	0.444	0.939	26.680	0.010	0.952
55.8	0.666	1.010	0.876	9.511	0.024	0.943
93.0	0.510	1.062	0.989	8.795	0.024	0.975

IV. CONCLUSION

The effect of temperature on flow behavior of pomegranate concentrate during evaporation process was studied. Pomegranate concentrate exhibits pesudoplastic flow behavior at all temperatures and concentrations studied. Two models were used to describe the effect of concentration on consistency index and activation energy.

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