J. King Saud Univ., Vol. **4**, *Agric. Sci.* (1), pp. 3-13, Riyadh (A.H. 1412 / 1992).

Viscometric Behavior of Single Strength and Concentrated Date-Water Extracts

B.H. Hassan
Department of Agricultural Engineering, College of Agriculture, King Saud University, Riyadh, Saudi Arabia

Abstract. Viscometric behavior of single strength and concentrated date-water extracts of the cultivar Anbari has been experimentally investigated using a concentric cylinders rotational viscometer. The date-water extracts in the concentration range 22.5%-78.5% (TS), temperature range 24.0-95.0°C, and shear rate range 2.5-979.0 $(Sec)^{-1}$, exhibited shear thinning behavior (pseudoplastic), evident from the consistent decrease of viscosity with increasing shear rate. Viscosity of all concentrations within the temperature and shear rate ranges investigated, was in the range 1.08-5622.61 m pa. sec.

The power law model described adequately the flow behavior of the date-water extracts at various concentrations and temperatures. The flow behavior index (n), and the consistency index (k) were within the ranges 0.57-0.98, and 6.49-5720.32 m pa. $(sec)^n$, respectively.

Introduction

Knowledge of the rheological behavior of food products is essential for process design and evaluation, quality control and consumer acceptability. Studies on rheological properties and different types of flow behavior of liquid foods has been reviewed by Holdsworth [1], Rao [2], and Rao *et al.* [3]. Relatively few studies have been carried out with viscometers capable of providing shear rate-shear stress data necessary to characterize the flow behavior of concentrated fruit juices and suspensions [4-8]. Likewise, few studies have dealt with the effect of temperature and concentration in a quantitative manner [3,5,9]. Viscosity is one of the most important rheological properties of liquid foods. A viscous liquid flows when a force is applied. According to Newton's law of viscous fluids, shear stress is directly proportional to shear rate. Some liquid foods such as milk and carbonated beverages are Newtonian [10-12]. The rheological properties of Newtonian liquids are independent of the shear rate and the previous shear histories, and are dependent only on temperature and composition [3,13]. Non-Newtonian liquids can be conveniently classified as either time-independent or time-dependent. For the former, at a constant temperature, the viscosity depends only on the magnitude of the shear rate [2,3,10,13]. If the viscosity decreases when the shear rate is increased the liquid is a shear thinning or more popularly a pseudoplastic liquid. If the viscosity increases as the shear rate is increased, the liquid is a shear thickening liquid. Sometimes, shear thickening liquids, are referred to as dialatant liquids [2, 14-16].

This study was conducted to experimentally determine the viscometric behavior of single strength and concentrated date-water extracts as a function of concentration, temperature, and shear rate.

Materials and Methods

Single strength date-water extract

The date cultivar Anbari at Tamr stage, was purchased from the local market and used in this study. 10 kg of the purchased dates were washed with tap water to remove extraneous materials and then transferred to a clean plastic bucket. Water was then added in the ratio 2.5: 1 (w/w. water: dates), and the date-water mixture was kept in a controlled temperature cold storage room at 5 ± 1°C to soak for 24 hr. The soaked mixture was then heated while mixing manually, in a double jacketted stainless steel kettle (Model TDC/2-20, Groen Div./Dover Corp. Etk Grove village, Illinois 60007, USA), using saturated steam at 543.1 kpa (T = 155°C). The initial temperature of the mixture was 17°C, and it reached 95°C after 5 min of heating. The mixture was then cooled to 50°C using cooling water at 27°C for 13 min. Pits and coarse solid materials were seperated from the mixture using a 2 mm mesh stainless steel seive. A second stage manual filtration was applied to the pits and coarse solids free extract using a fine mesh cheese cloth. The total solids of the final date extract (TS = 22.5%) was measured with a hand refractometer (Erma, Tokyo, No. 5317, W.S.R. 0-50).

Vacuum concentration of the extract

Part of the date-water final extract was vaccum concentrated using a pilot scale falling film evaporator (Luwa thin film evaporator, Pilot Plant LN 0012, SMS, GmbH, W. Germany). Evaporation process conditions were as follows: Feed total solids (TS) = 22.5%, feed inlet temperature = 14°C, feed flow rate = 618 ml/min, vacuum = 39 KPa, heating medium temperature (saturated steam) = 145°C, and concentrate outlet temperature = 77°C. The final total solids content of the concentrated extract was 78.5%.

Intermediate concentrations were prepared by mixing the single strength extract with the concentrated extract in a predetermined amounts calculated through mass balances and confirmed by refractometer measurements. Accordingly, the concentrations used in this study were 22.5%, 37%, 51.5%, 63%, and 78.5% (TS).

Viscometric measurements

A Haake viscometer (model viscotester VT. 181), together with a heating bath circulator (model F3-S), and a frequency converter (model FW) (HAAKE Mess-Technik Gmbtt U. Co. Diesel-strasse 4. D-7500 Karlsruhe 41, W. Germany) were used in this study as an integrated system for viscosity measurements, together with the sensor systems NV, MVI, MVII, and MVIII. A data aquisition system (Hewlett Packard, 30555 personal computer based data-Logger, P.O.Box 10301, Palo alto, USA) was used for sample temperature measurements.

The viscotester VT/181 is a concentric cylinders rotational viscometer. Each test sample was placed into the annular spaces between the two concentric cylinders of the sensor system used. While the inner cylinder was rotating at a defined speed (shear rate), the torque (shear stress), required was measured. Temperature was precisely controlled by the heating bath circulator, and the data aquistion system confirmed the accuracy of the sample temperature. Rheological parameters were measured in the temperature range 24-95°C. Each experiment was at least triplicated, and average data were used in calculations.

Results and Discussion

Viscometric behavior

Flow behavior is the result of the combined manifestation of a number of basic physical parameters. Rheological measurements determine the state of these parameters under the measured conditions, and the data are strongly dependent on the measurement conditions. Viscometric measurements represent the equilibrium state of the system under an imposed shear rate and the overall effect of forward and reverse structural changes under the shearing conditions.

Experimental shear stress-shear rate data at various temperatures for three of the investigated concentrations of the date-water extract are presented in Figs. 1-4. The shear rate ranges applied were 30.59-979.00 $(Sec)^{-1}$ for the 22.5%, 37%, and 51.5% (TS), 13.25-979.00 $(Sec)^{-1}$ for the 63% (TS), and 2.5-163.00 $(Sec)^{-1}$ for the 78.5% (TS) concentrations. The corresponding shear stress ranges were 71.0-2883.0

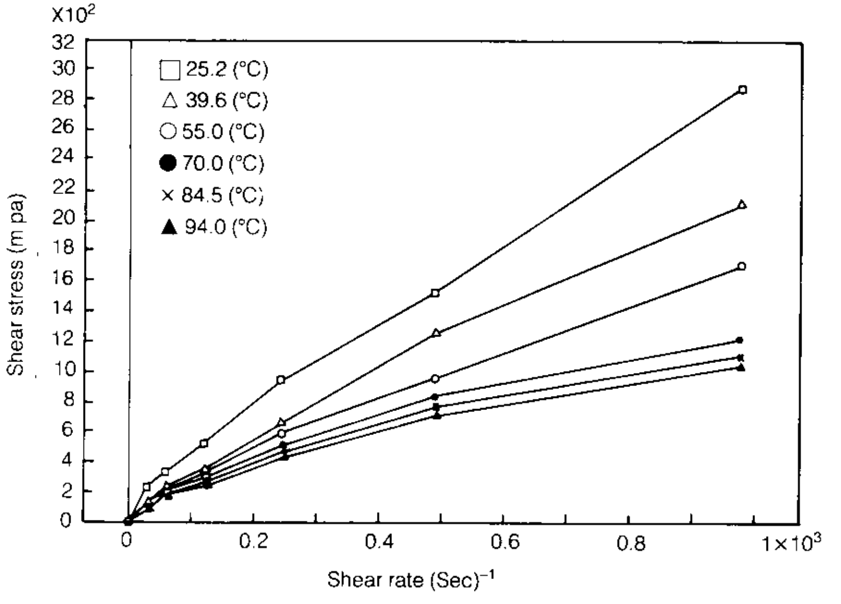

Fig. 1. **Shear stress VS. Shear rate for the 22.5% (TS) date-water extract concentration at different temperatures.**

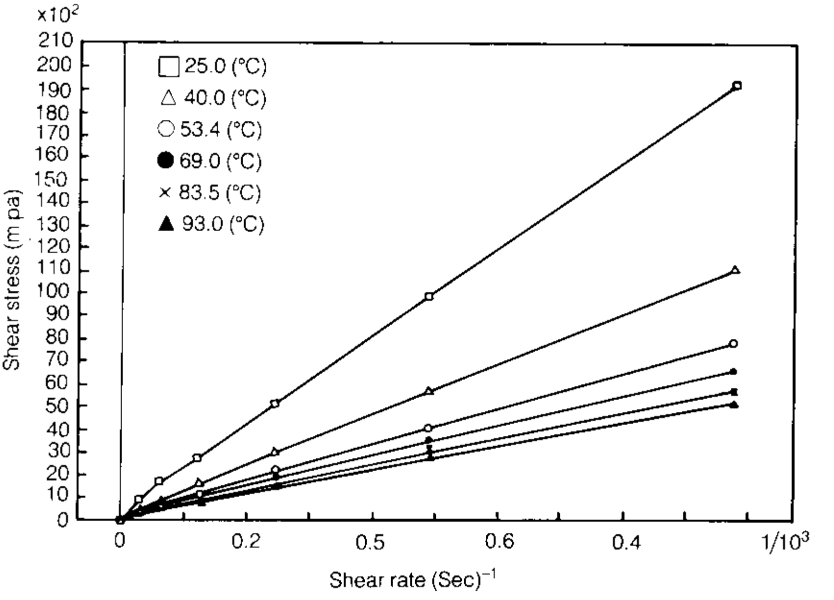

Fig. 2. **Shear stress VS. Shear rate for the 51.5% (TS) date-water extract concentration at different temperatures.**

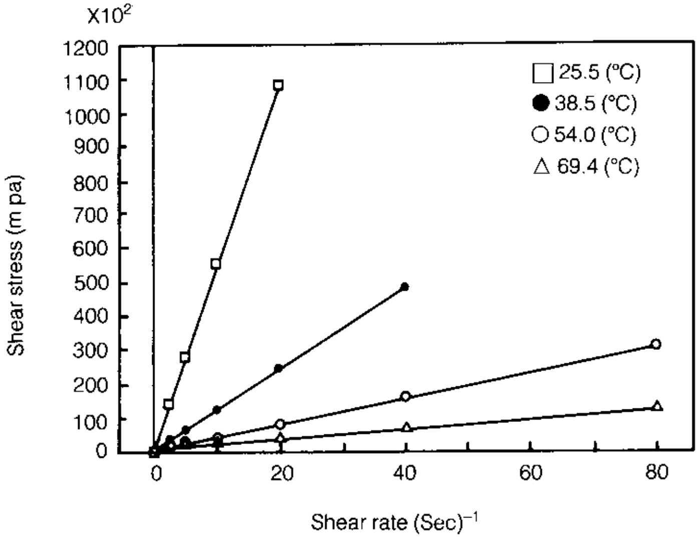

Fig. 3. **Shear stress VS. Shear rate for the 78.5% (TS) date-water extract concentration at different temperaturees.**

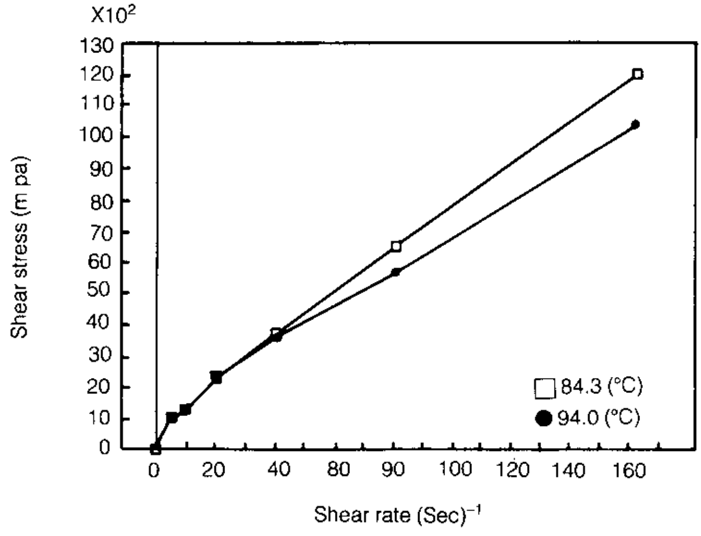

Fig. 4. **Shear stress VS. Shear rate for the 78.5% (TS) date-water extract concentration at higher temperatures.**

mpa, 353.0-5828.0 mpa, 235.0-19184.0 mpa, 603.0-36765.0 mpa, and 962.0-107748.0 mpa for the date water extract concentrations 22.5%, 37%, 51.5%, and 78.5% (TS), respectively. At lower and medium concentrations [22.5%, 37%, 51.5% (TS)], the shear stress-shear rate relationship was curvilinear with increasing linearity as temperature and shear rate increases. The shear stress increased significantly as concentration was increased from 22.5% to 51.5% (TS), indicating a significant increase in viscosity. The shear stress decreased with increasing temperature for all concentrations as expected. At higher concentrations [63% and 78.5% (TS)] and within the temperature range 24.8-69.5°C, the shear stress-shear rate relationship was very close to a linear relationship specially for the 78.5% (TS) concentration. Linearity was more pronounced at medium and high shear rates. However, at the higher temperature range 82.5-94°C, curvelinearity was more pronounced as compared to the former temperature range for the 78.5% (TS) concentration. The behavior of the shear stress-shear rate data in addition to the consistent decrease of viscosity with increasing shear rate, indicates that date-water extract within the ranges of concentrations, temperatures, and shear rates investigated were all Non-Newtonian. However, it must be stated that, at the 78.5% (TS) concentration, and within the temperature range 22.5-54.0°C, the concentrated extract was very close to the Newtonian behavior.

Effect of shear rate, temperature and concentration on viscosity

Viscosities of three of the investigated date-water extract concentrations as a function of shear rate and temperature are shown in Figs. 5-8. All of the figures depict a shear thinning behavior indicating that the single strength and concentrated date-water extracts are all pseudoplastic liquids. Within the shear rate and temperature ranges investigated, viscosity ranges were 1.08-7.68 mpa. sec, 2.8-13.82 mpa. sec, 6.81-28.42 mpa. sec, 14.6-288.27 mpa. sec. and 74.00-5622.61 mpa, sec, for the date-water extract concentrations 22.5%, 37%, 51.5%, 63% and 78.5% (TS), respectively. Viscosity increased with increasing concentration and decreasing temperature, as expected. However, temperature effect was more significant at higher concentrations.

The pseudoplastic behavior of the date-water extracts suggests a continuous breakdown or rearrangement of the structure, resulting in less resistance to flow. The presence of sugars (fructose, glucose, and sucrose) as the major compounds of the date-water extracts, with a relatively high molecular weights, is probably the most significant factor in explaining its rheological behavior. To quantitatively express flow and fit experimental data into an equation, the power law equation, is in general the most applicable.

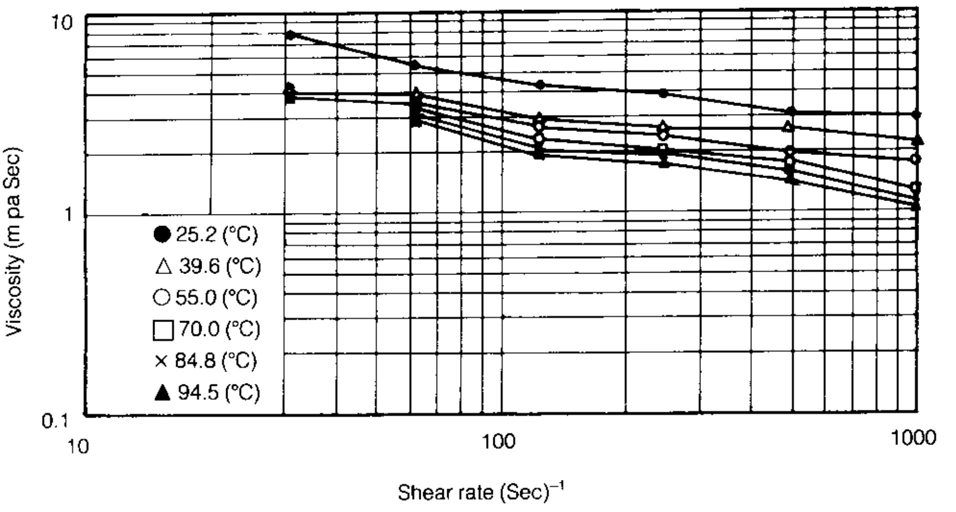

Fig. 5. Effect of shear rate and temperature on viscosity of the 22.5% (TS) date-water extract

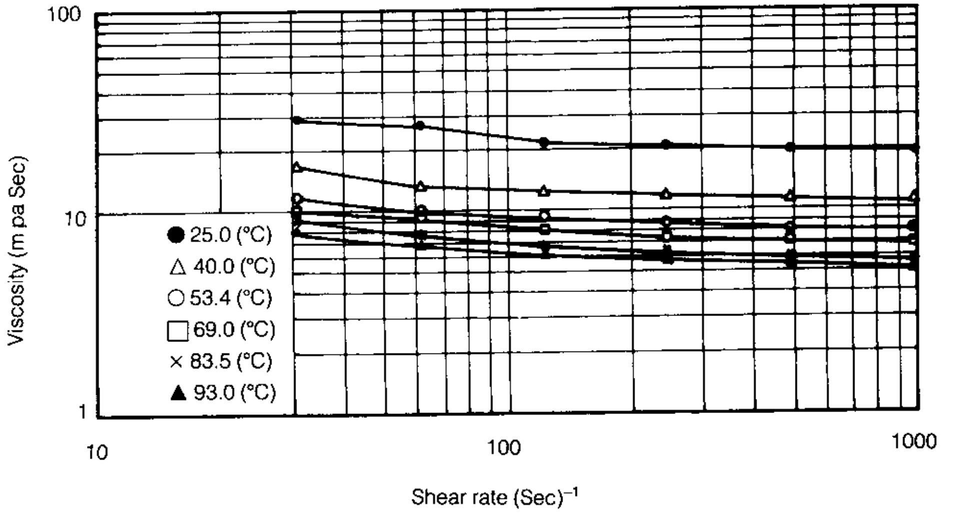

Fig. 6. Effect of shear rate and temperature on viscosity of the 51.5% (TS) date-water extract

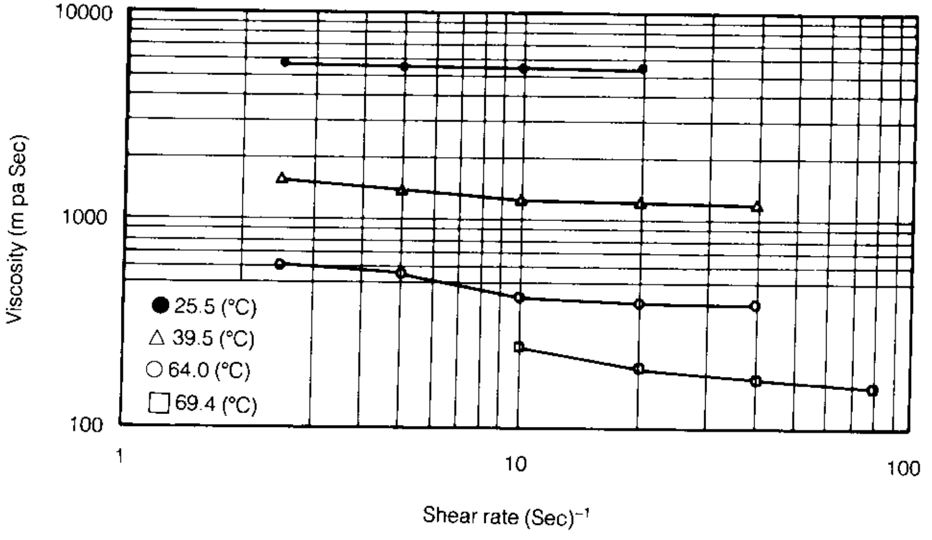

Fig. 7. Effect of shear rate and temperature on viscosity of the 78.5% (TS) date-water extract

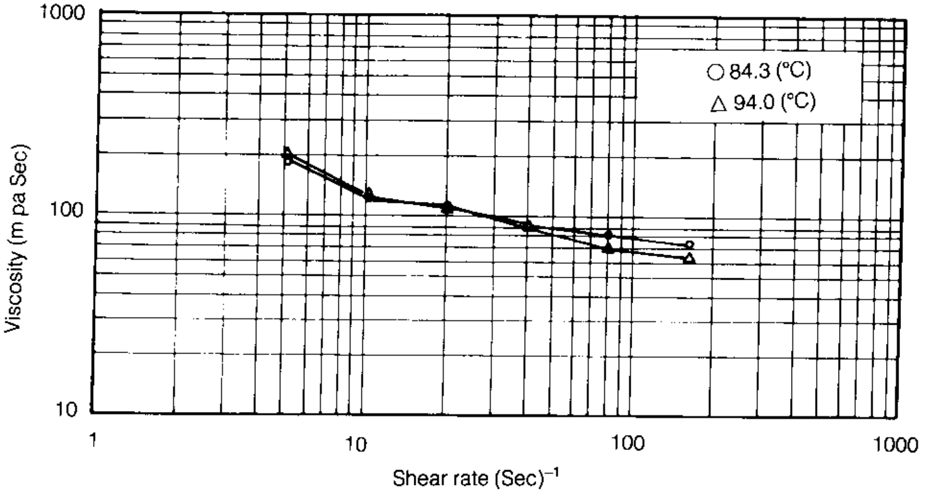

Fig. 8. Effect of shear rate and higher temperatures on viscosity of the 78.5% (TS) date-water extract

Table 1. Effect of date-water extract concentration and temperature on the flow behavior index (n) and the consistency index (k)

Extract conc. % (TS)	Temperature °C	n	mpa.^{k} (Sec)^n	R^2	Shear rate range Sec^{-1}	Shear stress range mpa
22.5	25.2	0.73	17.21	0.99	30.59 - 979.00	235.0 - 2883.0
	39.6	0.83	7.16	0.99	30.59 - 979.00	118.0 - 2115.0
	55.0	0.76	8.80	0.99	30.59 - 979.00	118.0 - 1716.0
	70.0	0.68	12.02	0.99	30.59 - 979.00	118.0 - 1222.0
	84.8	0.76	6.49	0.98	30.59 - 979.00	71.0 - 1112.0
	94.5	0.74	6.81	0.98	30.59 - 979.00	71.0 - 1058.0
37.0	25.0	0.76	19.18	0.99	30.59 - 979.00	423.0 - 5828.0
	39.5	0.69	29.95	0.99	30.59 - 979.00	360.0 - 3995.0
	54.5	0.64	32.91	0.96	30.59 - 979.00	353.0 - 3149.0
	69.0	0.61	33.44	0.94	30.59 - 979.00	353.0 - 2718.0
	84.0	0.57	40.63	0.94	30.59 - 979.00	353.0 - 2468.0
51.5	25.0	0.89	41.01	0.99	30.59 - 979.00	870.0 - 19184.0
	40.0	0.89	22.08	0.99	30.59 - 979.00	517.0 - 11022.0
	53.4	0.89	16.09	0.99	30.59 - 979.00	360.0 - 7841.0
	69.0	0.88	14.48	0.99	30.59 - 979.00	306.0 - 6666.0
	83.5	0.87	13.34	0.99	30.59 - 979.00	282.0 - 5679.0
	93.0	0.89	10.72	0.99	30.59 - 979.00	235.0 - 5178.0
63.0	24.8	0.90	292.97	0.99	13.25 - 212.00	2025.0 - 37665.0
	39.2	0.89	151.21	0.99	13.25 - 424.00	1654.0 - 32874.0
	54.0	0.87	85.82	0.99	13.25 - 424.00	848.0 - 17455.0
	69.0	0.86	44.88	0.98	30.59 - 424.00	854.0 - 8381.0
	83.5	0.92	27.32	0.98	30.59 - 979.00	658.0 - 15863.0
	93.0	0.91	25.38	0.98	30.59 - 979.00	603.0 - 14298.0
78.5	25.5	0.98	5720.32	1.00	2.50 - 20.00	14077.0 - 107748.0
	39.5	0.91	1919.45	0.99	2.50 - 40.00	3878.0 - 48293.0
	54.0	0.86	653.17	0.99	2.50 - 80.00	1528.0 - 30550.0
	69.4	0.80	365.82	0.99	5.09 - 80.00	1255.0 - 12690.0
	84.3	0.73	265.83	0.98	5.09 - 163.00	1027.0 - 12062.0
	94.0	0.70	273.71	0.99	5.09 - 163.00	962.0 - 10399.0

$$\tau = K\dot{\gamma}^n$$

This equation contains the shear stress (τ), consistency index (K), rate of shear $\dot{\gamma}$, and flow behavior index (n), and can represent Newtonian, Bingham plastic, pseudoplastic, and shear thickening properties, depending on the values of constants (K) and (n) [13, 15]. The linearized form of the power law equation together with the shear stress-shear rate experimental data were statistically analyzed using a linear regression software [17]. Results of the analysis are presented in Table 1. For all concentrations and all temperatures investigated the flow behavior index (n) was less than unity (0.57-0.98) which confirmed the pseudoplastic behavior of the date-water extracts. The consistency index (K) [6.49-5720.32 mp. $(\text{Sec})^n$] increased with increasing concentration and decreasing temperature. Further work is needed to develop a generalized mathematical correlation to predict viscosity of date-water extracts of different Saudi date cultivars as a function of concentration, temperature and shear rate.

References

[1] Holdsworth, S.D. "Application of Rheological Models to the Interpretation of Flow and Processing Behavior of Fluid Food Products". *J. Texture Studies.*, 2 (1971), 393-418.

[2] Rao, M.A. "Rheology of Liquid Foods A review". *J. Texture Studies.*, 8 (1977), 135-168.

[3] Rao, M.A., Cooley, H.J. and Vitali, A.A. "Flow Properties of Concentrated Juices at Low Temperatures". *Food Technol.*, 38 No. 3 (1984), 113-119.

[4] Harper, J.C. and El-Sahrigi, A.F. "Viscometric Behavior of Tomato Concentrates". *J. Food Sci.*, 30 (1965), 470-476.

[5] Chevalley, J. "Rheology of Chocolate". *J. Texture Studies.*, 6 (1975), 177-196.

[6] Rao, M.A., Bourne, M.C. and Cooley, H.J. "Flow Properties of Tomato concentrates". *J. Texture Studies*, 12 (1981), 521-529.

[7] Saravacos, G.D. "Effect of Temperature on Viscosity of Fruit Juices and Purees". *J. Food Sci.*, 35 (1970), 122-125.

[8] Mizrahi, S. and Berk, Z. "Flow Behavior of Concentrated Orange Juice". *J. Texture Studies*, 1 (1970), 342-355.

[9] Vitali, A.A. and Rao, M.A. "Flow Behavior of Guava Puree as a Function of Temperature and Concentration". *J. Texture Studies*, 13 (1982), 275-286.

[10] Rha, C.K. "Rheology of Fluid Foods". *Food Technol.*, 32 No. 7 (1978), 77-82.

[11] Heldman, D.R. and Singh, R.P. *Food Process Engineering.* 2nd ed., Westport, Connecticut: AVI Publishing Co., Inc., 1981.

[12] Earle, R.L. *Unit Operations in Food Processing.* 2nd ed., Oxford: Pergamon Press, 1983.

[13] Rha, C.K. Theories and Principles of Viscosity, Chapt. 2, In: *Theory, Determination, and Control of Physical Properties of Food Materials.* C.K. Rha (Ed.). Dordrecht, Holland: D. Reidel Pub. Co., 1975.

[14] Loncin, M. and Merson, R.L. *Food Engineering : Principles and Selected Applications.* New York: Academic Press, 1979.

[15] Charm, S.E. "Viscometry of non-Newtonian Food Materials". *Food Res.*, 25 (1960), 351-362.

[16] Rao, M.A. and Anantheswaran, R.C. "Rheology of Fluids in Food Processing". *Food Technol.*, 36 No. 2 (1982), 116-121.

[17] SAS. *SAS User's Guide.* Cary, NC : Statistical Analysis System Institute, Inc., 1982.

السلوك اللزوجي لمستخلصات التمر الخفيفة والمركزة

بكــري حسيــن حســن

قسم الهندسة الزراعية، كلية الزراعة، جامعة الملك سعود، الرياض،

المملكة العربية السعودية

ملخص البحث. تمت دراسة السلوك اللزوجي للمستخلصات الخفيفة والمركزة لصنف التمر عنبري باستخدام جهاز قياس لزوجة دوراني ذو اسطوانات متداخلة، ولقد استخدم الماء كمذيب في عملية الاستخلاص.

في حدود تركيزات المستخلصات ٢٢,٥٪- ٧٨,٥٪ (مواد صلبة كلية)، وحدود درجات الحرارة ٢٤-٩٥°م، وحدود معدلات القص ٢,٥-٩٧٩ (ثانية)$^{-1}$، كان السلوك اللزوجي لجميع المستخلصات سلوكًا شبه بلاستيكي نتيجة لانخفاض اللزوجة عند ازدياد معدل القص.

وتفاوتت قيم اللزوجة في الحدود ١,٠٨-٥٦٢٢,٦١ (ميلي باسكال. ثانية) لجميع التركيزات ودرجات الحرارة ومعدلات القص التي تم اختبارها.

ولقد وجد أن معادلة قانون الأس تعبر تعبيراً ممتازًا عن سلوك سريان مستخلصات التمر، وكانت قيم دليل سلوك السريان (n) في الحدود ٠,٥٧-٠,٩٨، وقيم معامل التماسك (k) في الحدود ٤٩,٦-٥٧٢٠,٣٢ ميلي باسكال (ثانية)^{n} على الترتيب.