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Flow Properties of Date Pastes Suspensions

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Abstract. The flow properties of pastes suspensions of two date cultivars, Suffri and Serri, were measured experimentally and modeled. Within the shear rate range 50 to 500 s^{-1}, temperature range 5 to 55°C, and suspension concentration range 22.34 to 29.79 (%TS), all date pastes suspensions exhibited a non-Newtonian (pseudoplastic) behavior. The flow behavior index (n) and the consistency index (K) fell in the range 0.226 to 0.445 and 0.949 to 7.302 ($Pa.s^n$), respectively, for the Suffri cultivar, and in the range 0.242 to 0.527 and 0.0.256 to 3.880 ($Pa.s^n$), respectively, for the Serri cultivar. At a shear rate of 100 s^{-1}, the activation energy of flow (E_a) varied from 13701.47 to 16780.15 (kJ/k mol) for the Suffri cultivar, and from 10521.37 to 17556.74 (kJ/k mol) for the Serri cultivar. Two models for prediction of apparent viscosity of the paste suspensions of each date cultivar as a function of concentration, temperature, and shear rate were validated. Both models fitted experimental data adequately.

Introduction

Date paste is prepared from moistened-pitted dates, which are finely minced and ground. Date paste suspensions are produced by mechanically mixing date paste with known amounts of water. Therefore, the concentration of a suspension depends on the amount of water added. Date pastes suspensions, being naturally sweet, can be used in the production of beverages, carbonated and non-carbonated, as well as for producing high concentrated extracts (Syrup or Dibbs), customarily used in home made confectioneries and bakeries or may be used as a highly nutritious drink [1, pp.171-173]. The suspensions of low grade dates can also be used as a raw material in the fermentation processes necessary for the production of yeast, vinegar, and medical and industrial alcohol [2].

The flow properties of fluid foods are of great importance to food processing operations and texture. Flow properties of food suspensions in particular have been extensively investigated by numerous researchers [3-5, 6, pp.9-15, 7-9]. Knowledge of flow properties is essential for the proper design and operation of food manufacturing processes. Operations such as handling, mixing, pumping, extraction, and filtration are involved in many such processes. In these situations the flow properties of food suspensions at different temperatures and concentrations need to be understood. Such data on date paste suspensions is not available in the open literature. Therefore, the objectives of the present study were to determine the flow properties of date paste suspensions, the effect of temperature and concentration on the flow behavior, and to fit popular flow models that are useful in design of relevant equipment and processes.

Materials and Methods

Fresh samples

Pastes of two different date cultivars, namely, Suffri, and Serri purchased from a local date factory were adopted. The pastes wrapped in low-density polyethylene bags were packaged inside 10-kg carton boxes. Factory procedures involved grading, washing, and pitting of sound whole dates, followed by fine mechanical grinding to render a homogeneous sticky paste. The dry basis moisture contents of fresh date pastes used in all test runs were 0.119 ± 0.005, and 0.123 ± 0.006 (g water/g dry matter) for the cultivars Suffri, and Serri, respectively. All pastes samples were kept refrigerated at 4°C prior to experimentation.

Preparation of suspensions

Predetermined amounts of potable water at room temperature (25°C) were used in the preparation of the date paste-water suspensions. The water was thoroughly mixed with the paste using a mechanical mixer on Dial 10 (model IKA-RW15, Laboratory Supply Company Ollmann and CoKG, 636 Friedberg, Hanauer Str.10, Henssen, Germany). Three suspensions of 1:2, 1:2.5, 1:3 date paste to water ratios by weight from each cultivar were used in the rheological measurements experiments. These three ratios were selected because they lie within the range of optimum values for preparation of date paste suspensions as reported by several investigators [1,10,11]. A summary of average moisture contents on dry basis and total solids for all suspensions samples is given in Table 1.

Table 1. Summary of moisture contents and total solids at different date paste to water ratios for the two date cultivars Suffri and Serri

Date cultivar	Date paste to water ratio (w/w)	Moisture content * (%, d.b.)	Total solids ** (% TS)
Suffri	1 : 2	235.72	29.79
	1 : 2.5	291.67	25.53
	1 : 3	347.63	22.34
Serri	1 : 2	236.90	29.68
	1 : 2.5	293.05	25.44
	1 : 3	349.20	22.26

*(g water/g dry matter) x100%

** (g dry matter/g suspension) x 100%

Rheological measurements

The rheological measurements were carried out with a Brookfield cone and plate digital rheometer (Brookfield DV-III Programmable Rheometer, Brookfield Engineering Laboratories, Inc., Stoughton, MA 02072-2398 USA). The apparatus is designed to measure rheological parameters of shear stress and viscosity at given shear rates. The rheometer was connected to a circulating water bath (Brookfield Refrigerated Bath/Circulator Model TC-500, Brookfield Engineering Laboratories, Inc., Stoughton, MA 02072-2398 USA) for precise temperature control.

The shear rates utilized for rheological measurements were within the range of 50 to 500 s^{-1}, and the temperature values at which the measurements were carried out were 5, 15, 25, 35, 45, and 55°C. All measurements were done at least in triplicate.

Results and Discussion

Rheological data

Experimental data showing variation of shear stress with shear rate for the suspensions of the pastes of the two date cultivars Suffri and Serri, at different temperatures are illustrated in Figs. 1 to 6, respectively. It is evident that all suspensions exhibited a pseudoplastic (shear thinning) flow behavior at all tested temperatures. Shear stress consistently increased with increasing shear rate and decreasing temperature. This non-Newtonian behavior can be attributed to the presence of sugars, which are high molecular weight substances, in addition to the dispersed solids in the fluid phase.

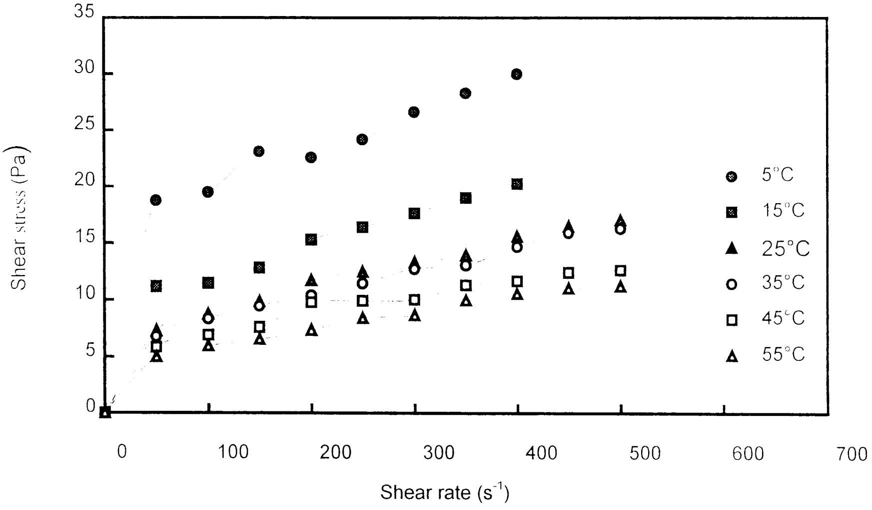

Fig.1. Shear stress vs shear rate for the 1:2 (date paste : water) suspension of Suffri cultivar.

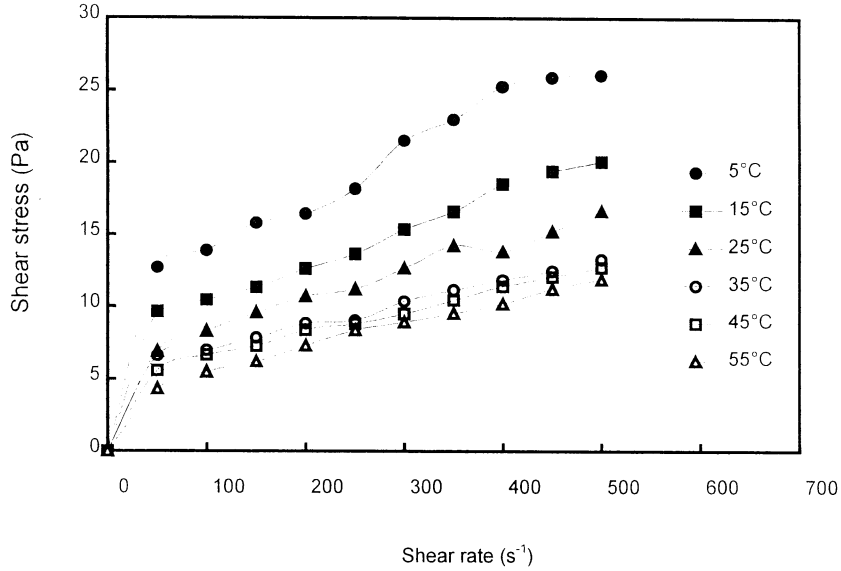

Fig. 2. Shear stress vs shear rate for the 1:2.5 (date paste : water) suspension of Suffri cultivar.

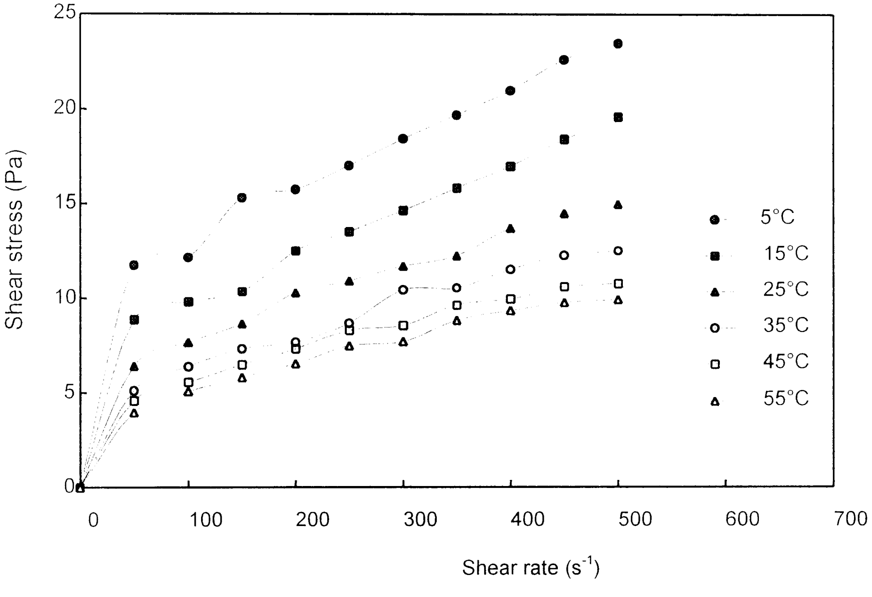

Fig. 3. Shear stress vs shear rate for the 1:3 (date paste : water) suspension of Suffri cultivar.

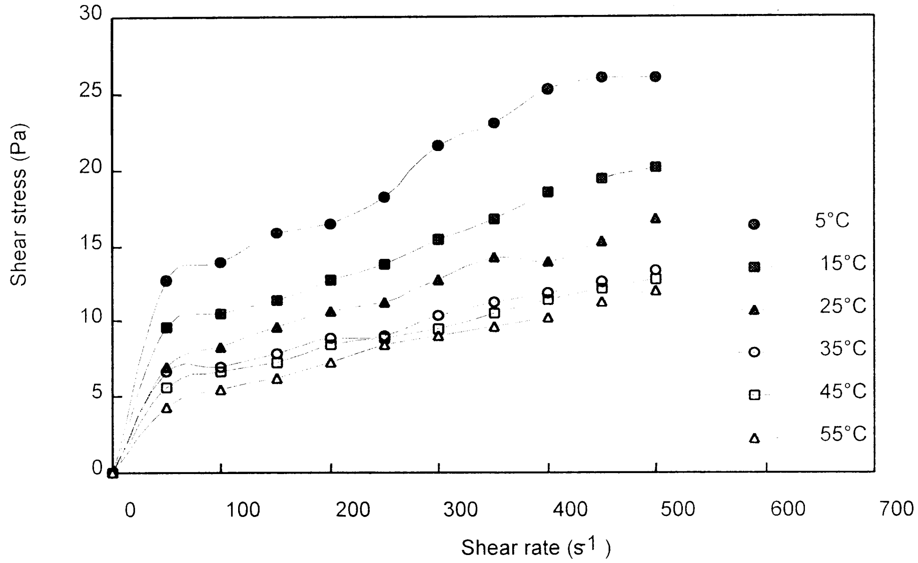

Fig. 4. Shear stress vs shear rate for the 1:2(date paste : water) suspension of Serri cultivar.

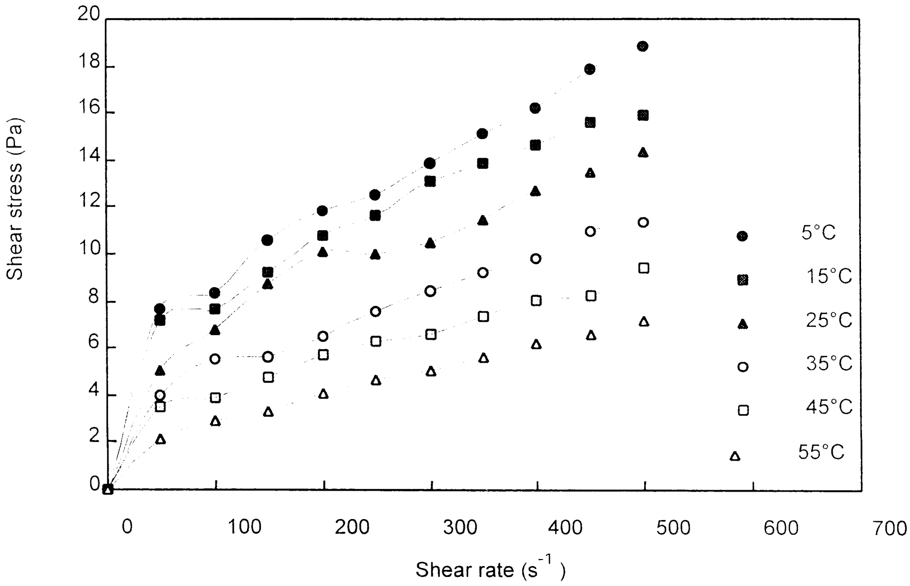

Fig. 5. Shear stress vs shear rate for the 1:2.5 (date paste : water) suspension of Serri cultivar.

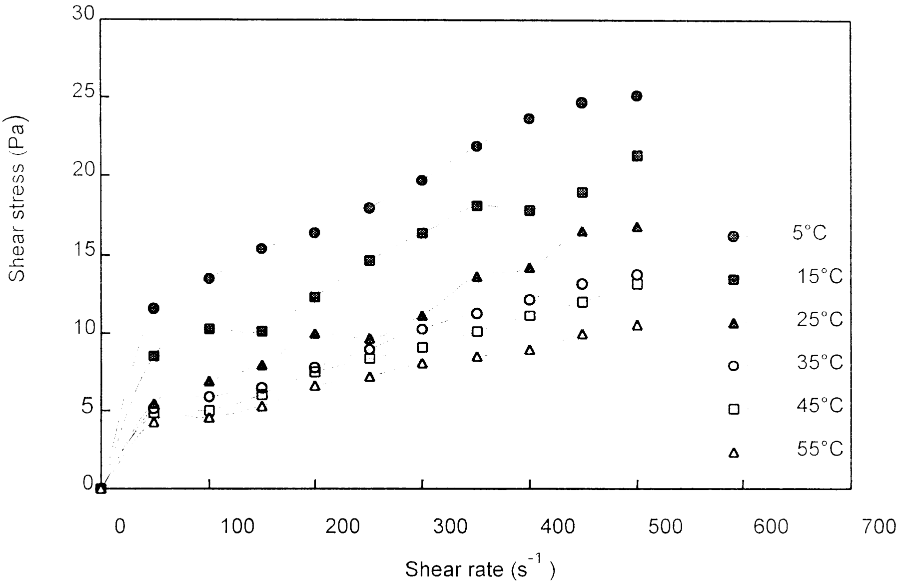

Fig.6. Shear stress vs shear rate for the 1:3 (date paste:water) suspension of Serri cultivar.

The rheological model most often used to describe the flow behavior of pseudoplastic foods is the power law, with or without a yield stress. Since no yield stress was detected for all concentrations and temperatures tested, the power law model without yield stress (Ostwald-de Waele model), as shown below, applies:

$$\tau = K\dot{\gamma}^{n} \tag{1}$$

where τ is the shear stress (Pa), $\dot{\gamma}$ is the shear rate (s^{-1}), K is the consistency index ($Pa.s^{n}$), and n is the flow behavior index. Linear regression was carried out [12] on the linearized form of Eq.1 using the experimental shear rate-shear stress data to determine values of the consistency index (K) and the flow behavior index (n). Table 2 shows results of the statistical analysis. It is clear that the power law model described well the shear rate-shear stress data as evident from the high values of the correlation coefficient (R^2). Values of the flow behavior index (n) ranged from 0.226 for the 1:2 Suffri suspension at 5°C, to 0.527 for the 1:2.5 Serri suspension at 55°C. These relatively low values indicate a strong pseudoplasticity (shear thinning) of the suspensions. Both rheological parameters (n) and (K) showed no consistent trend with temperature and concentration. Di Renzo and Colelli [9] reported the same behavior for olive paste.

Table 2. Flow behavior index (n) and consistency index (K) as a function of temperature and suspension concentration

Suspension concentration (Paste : water)	Rheological parameters	Temperature (°C)					
		5	15	25	35	45	55
Suffri 1:2	n	0.226	0.310	0.382	0.387	0.352	0.376
	K(Pa.s^n)	7.303	2.984	1.543	1.412	1.411	1.063
	R^2	0.903	0.913	0.982	0.978	0.971	0.972
1:2.5	n	0.351	0.345	0.365	0.325	0.363	0.445
	K(Pa.s^n)	2.830	2.208	1.584	1.652	1.258	0.716
	R^2	0.924	0.919	0.979	0.930	0.967	0.985
1:3	n	0.318	0.360	0.382	0.412	0.406	0.390
	K(Pa.s^n)	3.080	1.925	1.354	0.764	0.986	0.949
	R^2	0.943	0.935	0.982	0.988	0.971	0.989
Serri 1:2	n	0.307	0.242	0.307	0.348	0.346	0.342
	K(Pa.s^n)	3.880	3.535	2.202	1.652	1.583	1.401
	R^2	0.917	0.995	0.986	0.978	0.964	0.983
1:2.5	n	0.356	0.417	0.503	0.468	0.474	0.430
	K(Pa.s^n)	2.642	1.482	0.689	0.711	0.631	0.683
	R^2	0.965	0.931	0.952	0.947	0.934	0.950
1:3	n	0.407	0.385	0.438	0.457	0.442	0.527
	K(Pa.s^n)	1.401	1.428	0.920	0.630	0.554	0.256
	R^2	0.959	0.962	0.983	0.967	0.964	0.986

Effect of temperature and suspension concentration

Different temperatures are often encountered during processing, storage, transportation and consumption of liquid foods. For this reason their rheological properties are studied as a function of temperature. The Arrhenius relationship as shown in Eq.2 below has been extensively used to describe the effect of temperature on the apparent viscosity (μ_a) at a specified shear rate [8,13-20]:

$$\mu_a = \mu_\infty . \exp\left(\frac{E_a}{RT}\right) \tag{2}$$

where μ_a is the apparent viscosity in Pa.s, μ_∞ is a constant parameter in Pa.s, E_a is the activation energy of flow in kJ/ mol, R is the universal gas constant (8.314 kJ/ mol K), and T is the absolute temperature in degrees K.

Variation of apparent viscosity with temperature at a shear rate of 100 s^{-1} and different suspension concentrations of the date cultivars Suffri and Serri is illustrated in Figs. 7 and 8, respectively. Similar results were obtained for other shear rates. A linear regression analysis was carried out on the linearized form of Eq.2 using apparent viscosity values at the shear rate 100 s^{-1}. Table 3 shows obtained values of the activation energy of flow (E_a) and the constant parameter (μ_∞) for the suspensions of the two date cultivars Suffri and Serri.

Table 3. Activation energy of flow (E_a) and viscosity parameter (μ_∞) at 100 s^{-1} shear rate and various concentrations for the suspensions of the date cultivars Suffri and Serri

Suspension concentration (%TS)	E_a (kJ/k mol)	μ_∞ (Pa.s)	R^2
Suffri			
29.79	16780.15	0.0001	0.949
25.53	13443.74	0.0004	0.972
22.34	13701.47	0.0003	0.987
Serri			
29.68	17556.74	0.00005	0.968
25.44	14365.76	0.00020	0.985
22.26	10521.37	0.00015	0.962

Figures 7 and 8 indicate that the apparent viscosity of suspensions of the two date cultivars decrease with increasing temperature and decreasing concentration. However, there are variations in the flow behavior of the suspensions of the two date cultivars. Apparent viscosities of the Suffri suspensions were consistently higher than those of the Serri suspensions at the same concentration and temperature. In addition, effect of suspension concentration on viscosity was more pronounced for the Serri suspensions as compared to the Suffri suspensions. The activation energy of flow (E_a) decreased consistently with increasing concentration for the suspension of the Serri cultivar, however it was inconsistent for the 25.53 and 22.34 (%TS) concentrations of the Suffri cultivar as clear from Table 3. Also there was no consistent trend for the constant parameter (μ_∞) as a function of concentration for the suspensions of the two date cultivars. However, the statistical correlation was adequate as evident from the high values of the correlation coefficient (R^2).

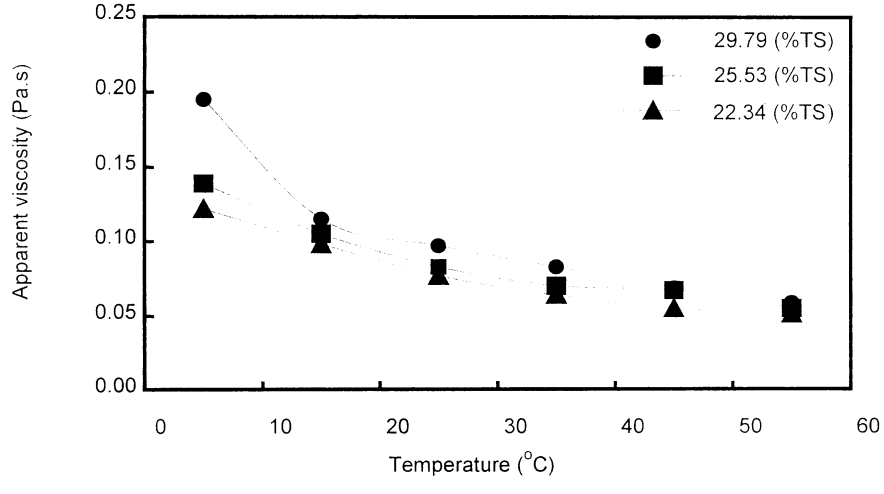

Fig. 7. Variation of apparent viscosity with temperature and concentration for the Suffri suspension at 100 s^{-1} shear rate.

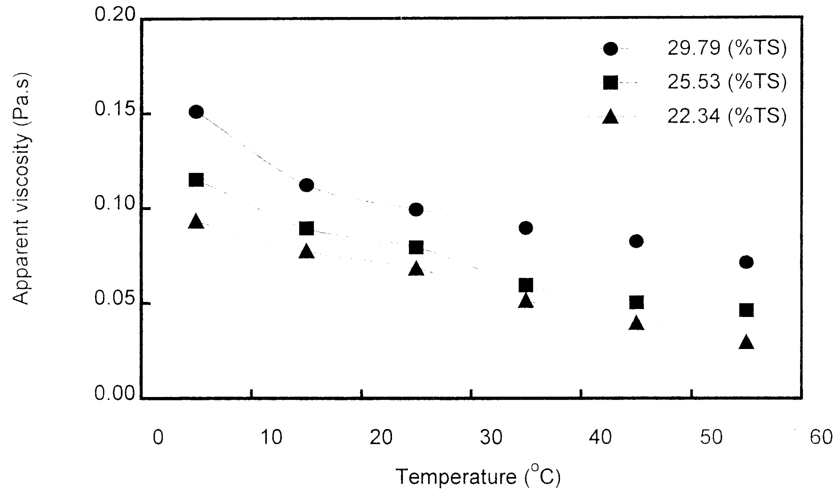

Fig. 8. Variation of apparent viscosity with temperature and concentration for the Serri suspension at 100 s^{-1} shear rate.

Concentration of non-Newtonian liquid foods can affect their apparent viscosities significantly. The exponential model, as shown in Eq.3 below, successfully correlated apparent viscosity (μ_a) with liquid food concentration (C) at constant shear rate and temperature as demonstrated by Rao *et al.* [17] for concentrated apple juice, by Hassan [19] for concentrated date extracts, and by Hassan and Hobani [20] for extracts of Roselle (Hibiscus *sabdariffa* L.):

$$\mu_a = \mu_1 . \exp(a_1 . C) \tag{3}$$

where μ_1 and a_1 are constant parameters. Values of the constant parameters μ_1 and a_1 were obtained by linear regression analysis of the linearized form of Eq.3, and results for the suspensions of the two date cultivars Suffri and Serri at the shear rate 100 s^{-1} are shown in Table 4. Results for other shear rates can be similarly determined.

Table 4. Constant parameters of equation (3) at 100 s^{-1} shear rate and different temperatures for the suspensions of the date cultivars Suffri and Serri

Temperature (°C)	Suffri			Serri		
	μ_1 (Pa.s)	a_1	R^2	μ_1 (Pa.s)	a_1	R^2
5	0.0291	0.063	0.970	0.0218	0.065	0.999
15	0.0611	0.021	1.000	0.0248	0.051	0.998
25	0.0544	0.016	0.958	0.0219	0.051	0.999
35	0.0292	0.035	0.990	0.0090	0.076	0.966
45	0.0268	0.024	0.910	0.0040	0.101	0.989
55	0.0334	0.0192	0.991	0.0021	0.119	0.990

Combined effect of temperature, concentration, and shear rate

Several investigators combined the effects of temperature, concentration, and shear rate to render the following generalized apparent viscosity model [8,14-17, 20-22]:

$$\mu_a = A_1.\exp\left(A_2.C + \frac{A_3}{T}\right).\dot{\gamma}^{A_4} \qquad (4)$$

where A_1 to A_4 are constant parameters. All experimental data (172 data points for each date cultivar) covering the shear rate range 50 to 500 s^{-1}, the temperature range 5 to 55°C, and the suspension concentration range 22.34 to 29.79 (%TS), were fitted by multiple linear regression of the linearized form of Eq.4 [12] to determine the constant parameters A_1 to A_4. Results of the statistical analysis for the suspensions of the two date cultivars Suffri and Serri are shown in Table 5. The high values of the correlation coefficient (R^2) and low values of the standard error of estimate (SEE) indicate the statistical adequacy of the two models. The two models should only be used within the experimental ranges investigated in this study.

Table 5. Models of Apparent viscosity as a function of temperature, concentration, and shear rate for the suspensions of the two date cultivars Suffri and Serri

Date cultivar	Model **	R^2	SEE
Suffri	$\mu_a = 2.817\times10^{-3}.\exp\left(27.93\times10^{-3}.C + \frac{1700.871}{T}\right).\dot{\gamma}^{-.638}$	0.975	0.091
Serri	$\mu_a = 1.251\times10^{-3}.\exp\left(51.77\times10^{-3}.C + \frac{1659.385}{T}\right).\dot{\gamma}^{-.599}$	0.947	0.129

**μ_a -apparent viscosity (Pa.s)
C -concentration (%TS)
T -absolute temperature (K)
$\dot{\gamma}$ - shear rate (s^{-1})

References

[1] Barreveld, W.H. "Products of Date Palms." *Agricultural Services Bulletin of FAO No. 101, FAO*, Italy: Rome, 1994.

[2] Hassan, B.H. "Possibilities of Date Processing in the Kingdom of Saudi Arabia." In: *Extension Book of Date Palms and Dates*, Agricultural Extension Center, College of Agriculture, King Saud University, Riyadh. 177-188,1996. (In Arabic).

[3] Rao, M.A. "Measurement of Flow Properties of Food Suspensions with a Mixer." *Journal of Texture Studies*, 6 (1975), 533-539.

[4] Rao, M.A. "Predicting the Flow Properties of Food Suspensions of Plant Origin." *Food Technology*, 41, No. 3 (1987), 85-88.

[5] Bhamidipati, S. and Singh, R.K. "Flow Behavior of Tomato Sauce with or Without Particulates in Tube Flow." *J. Food Process Engineering*, 12 (1990), 275-293.

[6] Kokini, J.L. "Rheological Properties of Foods." In: *Handbook of Food Engineering*, Dennis R. Heldman and Daryl B. Lund (Eds.) New York: Marcel Dekker,Inc, 1992.

[7] Bhattacharya, Sila and Bhattacharya, Suvendu. "Flow Behavior of Cooked Maize Flour Suspensions and Applicability of Mathematical Models". *J. Food Process Engineering*, 17, No. 3 (1994), 263-278

[8] Wang, Fangzhi and Meisen, Axel. "Flow Properties of Canola Seed Pastes." *Journal of Food Science*, 59, No. 5 (1994), 1091-1095.

[9] Di Renzo, G.C. and Colelli, G. "Flow Behavior of Olive Paste." *Applied Engineering in Agriculture*, 13, No. 6 (1997), 751-755.

[10] Benjamin, N.D, Abbas, M.F. and Shubbar, B.H. "Preparation and Clarification of Date Juice." *Journal of Agriculture and Water Research,* 1, No. 2 (1982), 75-87.

[11] El-Shaarawy, M.I, Mesallam, A.S, El-Nakhal, N.M. and Wahdan, A.N. "Studies on Extraction of Dates." *Proceedings of the Second Symposium on the Date Palm*, Al-Hassa: Saudi Arabia, 544-549.1986.

[12] SAS Institute. *SAS User's Guide in Statistics*. Cary, NC: SAS Institute Inc., 1987.

[13] Saravacos, G.D. "Effect of Temperature on Fruit Juices and Purees." *Journal of Food Science*, 35 (1970), 122-125.

[14] Rao, M.A. "Rheology of Liquid Foods: A Review." *Journal of Texture Studies*, 8, (1977), 135-168.

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

[16] Vitali, A.A. and Rao, M.A. "Flow Behavior of Guava Puree as a Function of Temperature and Concentration."*Journal of Texture Studies*, 12 (1981), 521-529.

[17] Rao, M.A, Cooley, H.J. and Vitali, A.A. "Flow Properties of Concentrated Juices at Low Temperatures." *Food Technology*, 13 (1982), 122-125.

[18] Constenla, D.T, Lozano, J.E. and Crapiste, G.H. "Thermophysical Properties of Clarified Apple Juice as a Function of Concentration and Temperature." *Journal of Food Science*, 54, No. 3 (1989), 663-686.

[19] Hassan, B.H. "Viscosity Models for Single Strength and Concentrated Date-Water Extracts." *Bulletin of Faculty of Agriculture, University of Cairo*, 42 (1991), 753-772.

[20] Hassan, B.H. and Hobani, A.I "Flow Properties of Roselle (*Hibiscuss sabdariffa l.*)." *Journal of Food Engineering*, 35, (1998), 459-470.

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

[22] Harper, J.M, Rhodes, T.P. and Waninger, L.P. "Viscosity Model for Cooked Cereal Doughs." *Chemical Engineering Progress Symposium Series*, 67, No. 108 (1971), 40-43.

خصائص السريان لمستعلقات معاجين التمور

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(قدم للنشر في٧/١١/ ١٤٢٠ وقبل للنشر في ١٩/٦/ ١٤٢١ هـ)

ملخص البحث. تم قياس خصائص السريان لمستعلقات معاجين صنفي التمور صفري وسري تجريبياً وتمثيلها بنماذج رياضية للتعبير عنها. في حدود معدلات القص من ٥٠ إلى ٥٠٠ (ث$^{-1}$) ودرجات الحرارة من ٥ إلى ٥٥ (^{o}م) ، وتركيز مستعلقات معاجين التمور من ٢٢,٣٤ إلى ٢٩,٧٩ (مواد صلبة كلية ٪) كان سلوك السريان غير نيوتوني (شبه بلاستيكي) لجميع مستعلقات معاجين التمور.تفاوتت قيم دليل سلوك السريان (n) ومعامل التماسك (K) في الحدود من ٠,٢٦٦ إلى ٠,٤٤٥ ، ومن ٠,٩٤٩ إلى ٧,٣٠٢ (باسكال. (ث)^{n})، على الترتيب، لصنف التمر صفري، وفي الحدود من ٠,٢٤٢ إلى ٠,٥٢٧ ، ومن ٠,٢٥٦إلى ٣,٨٨٠ (باسكال. (ث)^{n})، على الترتيب، لصنف التمر سري. عند معدل القص ١٠٠ (ث$^{-1}$) تفاوتت قيم طاقة التنشيط للسريان (E_a) في الحدود ١٣٧٠١,٤٧ إلى ١٦٧٨٠,١ (ك جول/ ك مول) لصنف التمر صفري، وفي الحدود ١٠٥٢١,٣٧ إلى ١٧٥٥٦,٧٤ (ك جول/ ك مول) لصنف التمر سري. وقد تم تقييم نموذجين رياضيين للتنبؤ باللزوجة الظاهرية لمستعلقات معاجين التمور لكل صنف كدالة للتركيز ودرجة الحرارة ومعدل القص. وقد عبر النموذجان الرياضيان بدرجة عالية عن كل النتائج التجريبية التي تم قياسها.