Cake filtration characteristics of date paste-water suspensions under constant pressure conditions

B.H. HASSAN and A.I. HOBANI

Agricultural Engineering Department, College of Agriculture, King Saud University, P.O. Box 2460, Riyadh 11451, Saudi Arabia. *Received 7 August 1993; accepted 1 August 1994.*

Hassan, B.H. and Hobani, A.I. 1994. **Cake filtration characteristics of date paste-water suspensions under constant pressure conditions.** Can. Agric. Engr. 36:143-149. Pilot scale filtration of date paste-water suspensions at three concentrations, namely, 1:1.5, 1:2, and 1:3 date paste to water ratios (w:w) were carried out at constant filtration pressures of 101.35 and 202.70 kPa (gauge). Two relevant mathematical models from published works on filtration of food systems were slightly modified to account for the non-Newtonian behavior of date paste-water filtrates and the filtration system used. Filtration parameters were statistically determined using pilot scale experimental data and the two modified filtration models. Both models were adequate in describing the filtration behavior, however one of the models is physically more sound as it includes some of the important physical properties of suspension, filtrate, and cake.

Filtration pilote de la suspension de patte des dattes mélangée dans l'eau utilisant trois proporetions (p:p) de concentration, 1:1.5, 1:2, et 1:3 a été faite avec deux pressions de filtration constantes de 101.35 et 202.70 kPa. Deux modèles mathématiques de travaux déjà publiés sur la filtration des systèmes d'alimentation ont été légèrement modifier, tenant compte du caractère non-Newtenien des filtres et le système de filtration utilisé. Les deux modèles ont été adéquats dans la description de caractère de filtration. En effet, un des modèles est physiquement plus logique comme il inclue quelque propriétés physique importantes de suspension, filtrage, et déposition solide.

INTRODUCTION

Many applications in the food and chemical industries use filtration for separation of suspensions to their respective liquid (filtrate) and solid (cake) constituents by passing through a permeable medium that retains the particles. Published investigations on filtration of food systems are limited (Peleg and Brown 1976; De La Garza and Boulton 1984; Bayindirli et al. 1989; Chang et al. 1989). Moreover, the nature of some food suspensions is complex owing to the non-Newtonian behavior of their filtrate and the compressible nature of their retained cakes. Murase et al. (1989) investigated filtration characteristics of power-law non-Newtonian suspensions using model systems and modified mathematical equations derived in previous works. They determined general filtration characteristics, namely; the ratio of wet to dry cake mass, the average specific filtration resistance, and the average cake porosity.

The present work was conducted using date paste-water suspension as the food system. This bears a twofold significance. First, the production of clear watery date extracts from which all insoluble matter has been filtered out is an essential process prior to pilot plant or industrial scale production of a number of date based products such as date syrup (dibbs), date juices and mixes, date soft drinks, date liquid sugar, industrial and medical alcohol and vinegar (Mustafa et al. 1982; Hamad et al. 1982; El-Sharawy et al. 1986; Mikki 1986; Hassan 1989). Consequently, pilot scale filtration data of date paste-water suspensions are expected to be very useful in the efforts of understanding their filtration behavior. Second, some available mathematical models describing filtration processes could be tested for their applicability in fitting pilot scale experimental data. Employing relevant mathematical models will ultimately result in a better design and selection of suitable equipment and process conditions. This study was carried out at a pilot plant level to determine filtration characteristics and identify suitable models for filtration of date paste-water suspensions under constant pressure conditions.

THEORETICAL BACKGROUND

In cake filtration, once a layer of particles has formed on the filtering medium, its surface becomes the filter medium. Solids deposited add to the thickness of the cake while the clear liquor passes through. The cake is therefore composed of bulky mass of particles of irregular shape, among which run small channels. The Sperry equation, which is widely used to predict the filtration behavior through filter cakes (Akers and Ward 1977; Loncin and Merson 1979; Svarovsky 1981; Coulson et al. 1985; Brennan et al. 1990) is expressed as:

$$\frac{dV}{dt}=\frac{\Delta PA}{\mu}\left[\frac{1}{\frac{\alpha cV}{A}+R_m}\right] \tag{1}$$

where:

- V = volume of filtrate collected in time t (m^3),
- t = time (s),
- ΔP = pressure difference across the filter (kPa),
- A = filtration area (m^2),
- μ = filtrate viscosity (Pa•s),
- α = specific cake resistance ($m\bullet kg^{-1}$),
- c = mass of solids per unit volume of filtrate (kg(solids)•m^{-3} (filtrate)), and
- R_m = filter medium resistance (m^{-1}).

However, Eq. 1 was completely unsatisfactory for describing constant pressure filtration of wine (De La Garza and Boulton 1984) and apple juice (Bayindirli et al. 1989) despite the Newtonian behavior of their filtrate (i.e. μ is constant at variable shear rate). De La Garza and Boulton (1984) modified Eq. 1 to the following two models:

$$\frac{dV}{dt}=\frac{\Delta PA}{\mu}\left[\frac{1}{\alpha c\left(\frac{V}{A}\right)^{a}+R_m}\right] \tag{2}$$

$$\frac{dV}{dt}=\frac{\Delta PA}{\mu}\left[\frac{1}{R_m \exp\left(\frac{bV}{A}\right)}\right] \tag{3}$$

where:

a = constant, and
b = exponential fouling coefficient (m^{-1}).

Equations 2 and 3 were appropriate for wine filtration, but Bayindirli et al. (1989) could only use Eq. 3 to adequately fit their experimental data for apple juice filtration.

In an experimental viscometric investigation, Hassan (1992) showed that date-water extracts are non-Newtonian. They exhibited a psuedoplastic behavior and adequately followed the power-law model. Consequently, it would not be appropriate to use either of the above filtration models directly since the filtrate viscosity is not constant but dependent on the rate of shear. Based on the power-law model for filtrate flow, i.e.

$$\tau=K\dot{\gamma}^{n} \tag{4}$$

where:

τ = shear stress (Pa),
K = filtrate consistency index ($Pa \bullet s^n$),
$\dot{\gamma}$ = shear rate (s^{-1}), and
n = flow behavior index.

Murase et al. (1989) suggested the following filtration model:

$$A^{n}\left(\frac{dt}{dV}\right)^{n}=\frac{K\gamma_{av}\,\rho\, s}{A\,\Delta P\,(1-m\,s)}\,[V+V_m] \tag{5}$$

where:

γ_{av} = average specific filtration resistance for power-law filtrates ($m^{2-n} \bullet kg^{-1}$),
ρ = density of the liquid ($kg \bullet m^{-3}$),
s = mass fraction of solids in slurry,
m = ratio of wet to dry cake mass, and
V_m = fictitious filtrate volume (m^3).

Murase et al. (1989) used the fictitious volume V_m in Eq. 5 instead of the filter medium resistance R_m due to the special design of the filtration system they used. Their test filter was equipped with a disk having a hole on top of the filter chamber. The system works on the basis of the principle of sudden reduction in filtration area of the cake surface.

MATERIALS AND METHODS

Date paste of the variety Sarri was provided by a local date factory, wrapped in a low density polyethylene bag inside a packaging carton. Each package contained 10 kg of date paste. Factory operations included grading, washing, and pitting of sound whole dates, followed by fine mechanical grinding to render a homogeneous sticky paste. The average moisture content of the date paste used in all experiments was 8.7± 1.9 % (w.b.). 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 & CoKG, 636 Friedberg, Hanauer Str.10, Henssen, Germany). Three suspensions of 1:1.5, 1:2, and 1:3 date paste to water ratios were used in the pilot scale filtration experiments.

A pilot scale plate and frame sheet filter (Pilot A20Z, Seitz-Werke Gmbh, Kreuznacher Postfach 1049, Germany) was used as the filtration equipment. A stainless steel vessel for dissolving, mixing, and feeding of liquids and suspensions under sterile conditions (model D B60A, Seitz Enzinger No l, Maschinenbau Aktiengesellschaft, Manheim l, Postfach 645, Germany) was utilized as a containing and feeding vessel for suspension. The pressure vessel was directly connected to a pilot plant compressed air line using a flexible plastic hose. Another flexible plastic hose connected the outlet of the pressure vessel to the inlet of the sheet filter. The regulating valve and the pressure gauge on the pressure vessel, besides the pressure gauge on the sheet filter allowed adequate control of the filtration pressures used. Due to the limitation of the operating pressure of the vessel, only two filtration pressures, i.e., 101.35 kPa and 202.70 kPa were used in the pilot scale filtration experiments. The filter sheet used was type: Seitz-EK (Seitz-Filter-Werke Theo and Geo Seitz Gmbh und Co., D-6550 Bad Kreuznach, Germany).

Seventeen filter sheets corresponding to sixteen filter plates and two end plates, with 0.03 m^2 filtration area per sheet (0.51 m^2 total effective filtration area) were used in all experiments. For each of the three date paste to water suspension ratios, filtration experiments were carried out under the two pressures and each pilot scale experiment was duplicated. Graduated cylinders (2000 mL) were used for filtrate collection and times for collecting each 200 mL of the filtrate were recorded. Moisture contents for suspension, filtrate, and cake were determined using standard AOAC (1980) procedures. An Abbe refractometer (model Abbe Mark II, Digital refractometer, Cambridge Instrument Inc., Buffalo, NY) was used for determination of the total soluble solids (% TSS), degree Brix (sucrose), and the refractive index of suspension and filtrate, while their pH was determined using a pH meter (model pH 6000 meter, Sargent-Welch Scientific Co., Skokie, IL), and their density using a glass pycnometer. Viscometric measurements of the filtrate were carried out at room temperature (25°C) using a Haake viscometer, model viscotester VT181 (Haake Mess-Technik Gmbh U. Co. Diesel-Strasse 4, D-7500 Karlsruhe 41, Germany) as described by Hassan (1992). Each test sample was placed into the annular spaces between the two concentric cylinders of the viscometer. While the inner cylinder was rotating at a defined speed (shear rate), the torque (shear stress) required was measured. The shear rates tested were within the range 30.59-979.00 s^{-1}. The filtration system is illustrated in Fig. 1.

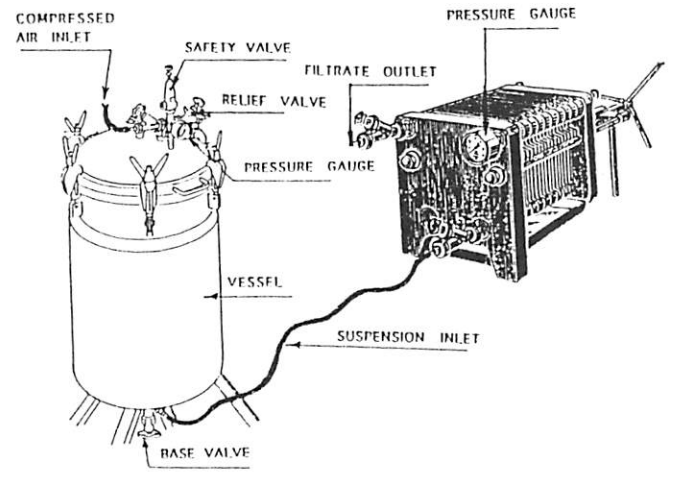

Fig. 1. Pilot scale filtration system (Adapted from manuals by Seitz-Werke GmbH, Kreuzancher, Postfach 1049 and Maschinenbau Aktiengesellschaft, Manheim 1, Postfach 645, Germany).

RESULTS AND DISCUSSION

The flow curves of the filtrates, which were found by the concentric cylinder rotational viscometer, are shown in Fig. 2. The non-Newtonian behavior of filtrates from all filtration experiments exhibited characteristics of pseudoplastic liquids as evident from the values of the flow behavior index, n. The linear regression module of a statistical software (Statgraphics 1989) was used in computing the power-law type of flow behavior characteristics as presented in Table I. Average values of relevant physical properties of suspension, filtrate, and cake are shown in Table II.

Filtration curves plotted as filtrate volume, V, versus filtration time, t, are illustrated in Figs. 3 and 4 for the three date paste to water ratios and at the two tested constant filtration pressures 101.35 kPa and 202.70 kPa, respectively. The rate of filtrate flow decreased as the concentration of suspension increased for both of the constant filtration pressures. However, the rates were very close for the 1:3 and 1:2 date paste to water ratios at 202.70 kPa, probably due to the compressibility behavior of the cake at these suspension concentrations. At the higher filtration pressure (202.70 kPa) the rate of filtrate flow was consistently higher than at the lower filtration pressure (101.70 kPa) for all of the three date paste to water ratios. The collected filtrate increased in color intensity (more dissolved soluble solids) as the filtration process proceeded, presumably due to the complicated nature of cake formation and its compressibility behavior besides the structure matrix of the filter sheet.

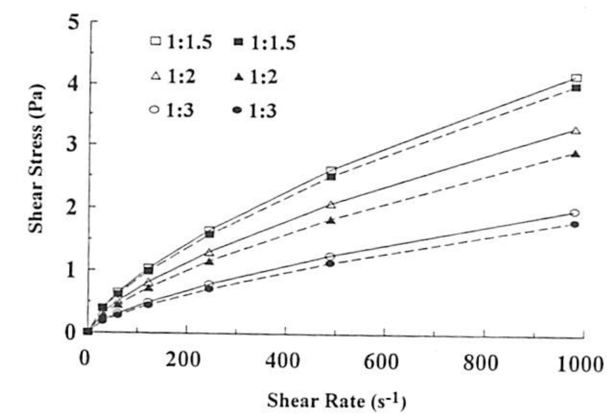

Fig. 2. Shear stress vs. shear rate for filtrates of the suspensions of the three date paste to water ratios at two constant filtration pressures.

A double check for the applicability of Sperrys' model (Eq. 1) was performed by plotting the experimental values of dt/dV versus the average filtrate volume, V, using the method suggested by McCabe and Smith (1976). The relations for the tested experimental combinations are illustrated in Figs. 5 and 6, showing significant variation from linearity. Therefore, in addition to the pseudoplastic behavior of the filtrate, the reciprocal form of Eq. 1 is nonlinear with respect to the experimental data. The model suggested by Murase et al. (1989), as presented in Eq. 5, is more appropriate. However, a minor modification is necessary to account for the difference between the filtration system they used and the pilot scale sheet filter used in this study. The minor modification is to replace the fictitious volume, V_m, in Eq. 5 by the filter medium resistance, R_m, to yield:

$$\left(\frac{dt}{dV}\right)^n = \frac{K}{\Delta P A^n}\left[\frac{\gamma_{av}\,\rho\,S}{A\,(1-m\,s)}\,V + R_m\right] \tag{6}$$

Further, the models suggested by De La Garza and Boulton (1984) as presented in Eqs. 2 and 3 can be tested upon modification to account for the non-Newtonian behavior of the filtrate, as:

$$\left(\frac{dt}{dV}\right)^n = \frac{K}{\Delta P\,A^n}\left[\frac{\alpha c}{A}\,V + R_m\right] \tag{7}$$

$$\left(\frac{dt}{dV}\right)^n = \frac{K}{\Delta P\,A^n}\left[R_m \exp\left(\frac{bV}{A}\right)\right] \tag{8}$$

Taking the logarithms of both sides of Eq. 8 yields:

$$\ln\left(\frac{dt}{dV}\right) = \frac{b}{n\,A}\,V + \frac{1}{n}\ln\left(\frac{K}{\Delta P\,A^n}\,R_m\right) \tag{9}$$

The form similarities of Eqs. 6 and 7 can be readily noticed. In fact the two equations are identical, since a material balance over suspension, cake, and filtrate yields (Akers and Ward 1977):

$$c = \frac{\rho\,s}{\left(1 - \dfrac{s}{s_c}\right)} = \frac{\rho\,s}{(1 - m\,s)} \tag{10}$$

where:

c = mass of dry solids per unit volume of filtrate, and

s_c = average mass fraction of solids in cake (kg solids•kg^{-1} cake).

Hence, γ_{av} in Eq. 6 is equivalent to α in Eq. 7.

Plots of the experimental values of ln (dt/dV) versus average filtrate volume, V, and their best fit lines for the constant

Table I: Flow behavior index (*n*) and consistency index (*K*) at room temperature (25 °C) for filtrates from all experimental combinations. ($\log \tau = \log K + \log \gamma$)*

Date paste : water	Filtration Pressure = 101.35 kPa				Filtration pressure = 202.70 kPa			
	n	*K* (10^{-3} Pa•s^n)	SEE	R^2	*n*	*K* (10^{-3} Pa•s^n)	SEE	R^2
1 : 1.5	0.67	41.42	1.73×10^{-4}	1.00	0.67	39.75	1.85×10^{-4}	1.00
1 : 2	0.67	32.64	1.35×10^{-2}	0.99	0.67	29.18	1.26×10^{-4}	1.00
1 : 3	0.67	18.08	2.00×10^{-4}	1.00	0.67	19.86	4.21×10^{-5}	1.00

* Shear rate range 30.59 - 979.00 s^{-1}

*P - values (prob. levels) were consistently equal to zero for all combinations.

SEE = Standard Error of Estimate

R^2 = Coefficient of determination

Table II: Average physical properties of suspension, filtrate, and cake for all experimental combinations

Material	Date paste : water ratio	Constant filtration pressure (kPa)	% M.C. (w.b.)	% Total solids (w.b.)	% Total soluble solids	°Brix (Sucrose)	Refractive index	pH
Suspension	1 : 1.5	101.35	62.8	37.3	35.4	35.2	1.391	5.64
	1 : 1.5	202.70	62.4	37.6	35.8	35.7	1.384	5.60
	1 : 2	101.35	70.8	29.2	26.1	26.0	1.374	5.71
	1 : 2	202.70	69.6	30.4	26.8	26.7	1.375	5.76
	1 : 3	101.35	77.4	22.6	20.5	20.2	1.364	5.71
	1 : 3	202.70	76.9	23.1	20.6	20.5	1.365	5.85
Filtrate	1 : 1.5	101.35	69.2	30.8	29.0	28.7	1.379	5.90
	1 : 1.5	202.70	71.8	28.2	26.0	25.9	1.374	5.80
	1 : 2	101.35	77.1	22.9	22.3	22.2	1.368	5.85
	1 : 2	202.70	75.9	24.1	22.6	22.5	1.368	5.90
	1 : 3	101.35	81.1	18.4	18.0	17.8	1.360	5.80
	1 : 3	202.70	80.7	19.3	18.1	17.9	1.360	5.94
Cake	1 : 1.5	101.35	57.1	42.9	-	-	-	-
	1 : 1.5	202.70	58.1	41.9	-	-	-	-
	1 : 2	101.35	63.6	36.4	-	-	-	-
	1 : 2	202.70	63.7	36.3	-	-	-	-
	1 : 3	101.35	70.8	29.2	-	-	-	-
	1 : 3	202.70	70.4	29.6	-	-	-	-

filtration pressures 101.35 kPa and 202.70 kPa are illustrated in Figs. 7 and 8, respectively. To evaluate the filtration characteristics for the constant pressure filtration of the tested concentrations of the date paste-water suspensions, using the experimental data and the modified models (Eqs. 6 and 9), a linear regression analysis for Eqs. 6 and 9 and a nonlinear regression analysis for Eq. 8 were carried out using the statistical software Statgraphics. Results of the evaluated filtration characteristics are presented in Table III.

The values of the filter medium resistance, R_m, as calculated using Eqs. 6, 8, and 9 increased with increasing pressure and decreasing suspension concentration except for the 1:2 date paste to water ratio at 101.35 kPa. Values of R_m from Eqs. 8 and 9 were consistently higher than the ones from Eq. 6 for all suspension concentrations at the two tested pressures. The nonlinear regression of Eq. 8 rendered slightly higher values of R_m as compared to the R_m values of the linear regression of Eq. 9. However, no consistent trend was observed on the values of the exponential fouling coefficient *b* for the two equations. The average specific filtration resistance of power-law filtrates γ_{av} as defined in Eq. 6 also increased consistently with increasing pressure and decreasing suspension concentration except for the 1:3 date paste to water ratio at 202.70 kPa. The parameter *b* in Eqs. 8 and 9 defined by De La Garza and Boulton (1984) as the exponential fouling coefficient, bears different units and hence cannot be compared to the values of γ_{av}.

Despite the statistical adequacy of Eqs. 6 and 8 or 9 in

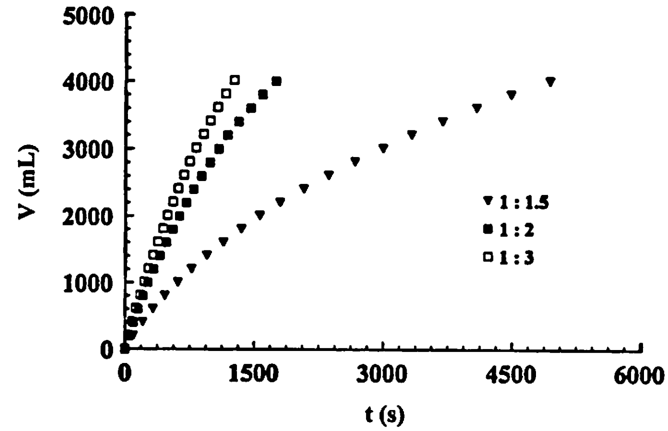

Fig. 3. Filtrate volume (*V*) vs. filtration time (*t*) for the three date paste to water ratios at 101.35 kPa constant filtration pressure.

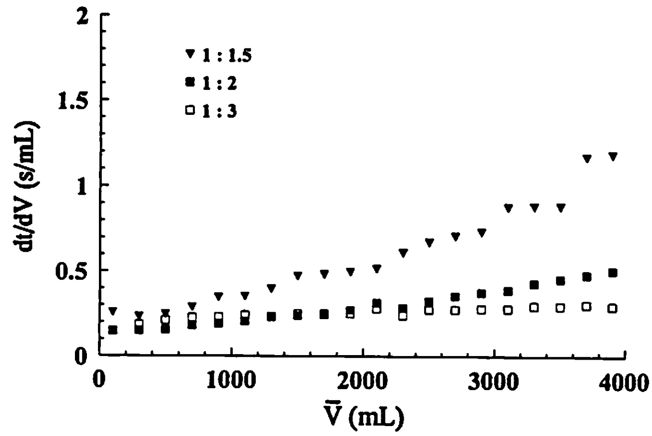

Fig. 6. dt/dV vs. $\bar{V}$ for the three date paste to water ratios at a constant filtration pressure of 202.70 kPa.

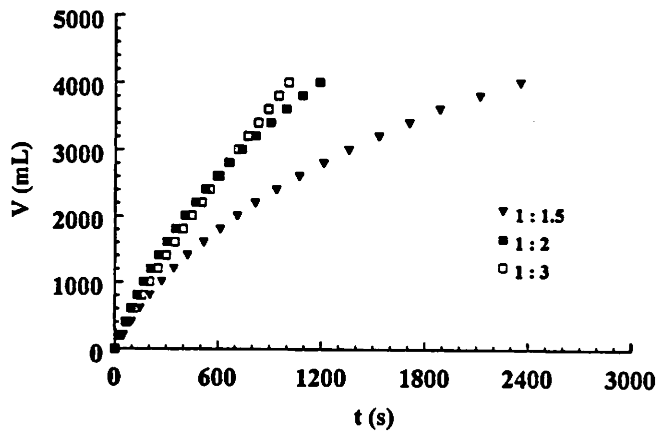

Fig. 4. Filtrate volume (*V*) vs. filtration time (*t*) for the three date paste to water ratios at 202.70 kPa constant filtration pressure.

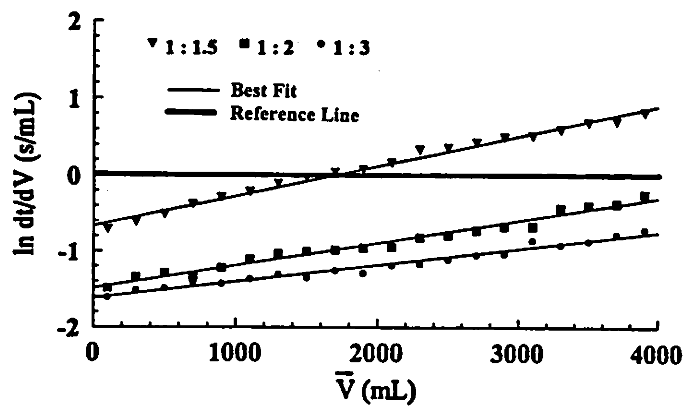

Fig. 7. ln dt/dV vs. $\bar{V}$ for the three date paste to water ratios at a constant filtration pressure of 101.35 kPa (Experimental data on best fit lines).

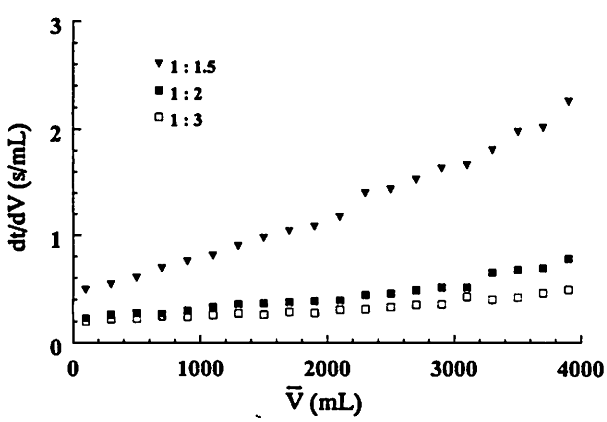

Fig. 5. dt/dV vs. $\bar{V}$ for the three date paste to water ratios at a constant filtration pressure of 101.35 kPa.

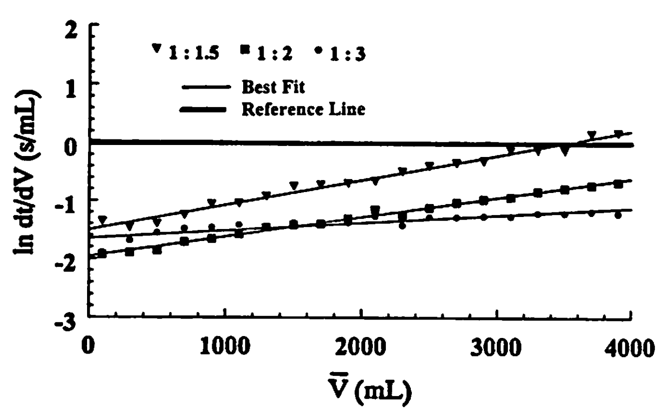

Fig. 8. ln dt/dV vs. $\bar{V}$ for the three date paste to water ratios at a constant filtration pressure of 202.70 kPa (Experimental data on best fit lines).

Table III: Filtration parameters for the three date paste : water suspensions ratios at the two tested constant filtration pressures as calculated statistically using the experimental data and the modified filtration models

Date paste : water ratio	Constant filtration pressure (kPa)	Equation (6)*				Equation (9)*				.Equation (8)**		
		γ_{av} ($m^{2-n} \bullet kg^{-1}$)	R_m (m^{-n})	SEE	R^2	b (m^{-1})	R_m (m^{-n})	SEE	R^2	b (m^{-1})	R_m (m^{-n})	R^2
1 : 1.5	101.35	5.05×10^8	9.18×10^9	281.93	0.994	132.87	10.46×10^9	0.051	0.989	126.80	10.73×10^9	0.989
	202.70	6.58×10^8	10.22×10^9	460.66	0.965	146.40	12.38×10^9	0.067	0.984	145.45	12.43×10^9	0.983
1 : 2	101.35	8.28×10^8	7.13×10^9	343.59	0.947	101.56	7.65×10^9	0.056	0.977	105.02	7.66×10^9	0.974
	202.70	12.20×10^8	11.27×10^9	138.94	0.987	114.92	12.44×10^9	0.039	0.991	112.82	12.54×10^9	0.992
1 : 3	101.35	12.81×10^8	12.08×10^9	195.91	0.951	74.41	12.62×10^9	0.045	0.972	76.70	12.48×10^9	0.971
	202.70	10.50×10^8	22.42×10^9	188.49	0.837	45.07	22.46×10^9	0.082	0.791	42.29	22.76×10^9	0.817

* Linear regression

** Non linear regression

predicting the filtration behavior of non-Newtonian type filtrates, Eq. 6 is more realistic from a physical point of view. The derivation of Eq. 6 (Murase et al. 1989) allowed appearance of the important physical properties instead of lumping them in one constant as presented in Eqs. 8 and 9.

CONCLUSIONS

Minor modifications of two relevant mathematical models for cake filtration of food systems were adequate to describe pilot scale plate and frame sheet filter performance for constant pressure filtration of the non-Newtonian filtrates of date paste-water suspensions. Both models can be used to interpret constant pressure filtration of similar non-Newtonian food systems.

REFERENCES

Akers, R.J. and A.S. Ward. 1977. Liquid filtration theory and filtration pretreatment. In *Filtration Principles and Practice*, Part 1, ed. C. Orr. New York, NY: Marcel Dekker, Inc.

AOAC. 1980. *Official Methods of Analysis*, 15th ed. Association of Official Analytical Chemists, Washington, DC.

Bayindirli, L., M. Ozilgen and S. Ungan. 1989. Modeling of apple juice filtration. *Journal of Food Science* 54(4):1003-1006.

Brennan, J.G., J.R. Bullers, N.D. Cowell and A.E. Lilley. 1990. *Food Engineering Operations*, 3rd ed. Essex, UK: Elsevier Science Publishers Ltd.

Chang, S.Y., R.T. Toledo and H.S. Lillard. 1989. Filtrate flow through filter cakes which exhibit time dependent resistance. *Journal of Food Processing and Preservation* 12:253-269.

Coulson, J.M., J.F. Richardson, J.R. Backhurst and J.H. Harker. 1985. Filtration. In *Chemical Engineering*, 3rd ed. 2:321-327. Oxford, UK: Pergamon Press.

De La Garza, F. and R. Boulton. 1984. The modeling of wine filtration. *American Journal of Enology and Viticulture* 35:189-195.

El-Sharawy, M.T., A.S. Mesallam, H.M. El-Nakhal and A.N. Wahdan. 1986. Studies on extraction of dates. In *Proceedings of the Second Symposium on the Date Palm in Saudi Arabia*, 259-269. King Faisal University, Al - Hassa, Saudia Arabia.

Hamad, A.M., A.I. Mustafa and M.S. Al-Kahtani. 1982. Possibility of utilizing date syrup as a sweeting and flavoring agent in ice cream making. In *Proceedings of the First Symposium on the Date Palm in Saudi Arabia*, 544-550. King Faisal University, Al - Hassa, Saudia Arabia.

Hassan, B.H. 1989. Possibilities of date industrialization in Saudi Arabia. In *Extension Book of Date Palms and Dates*. Agricultural Extension Center, College of Agriculture, King Saud University, Riyadh, Saudi Arabia. (In Arabic).

Hassan, B.H. 1992. Viscometric behavior of single-strength and concentrated date-water extracts. *Journal of King Saud University, Agricultural Sciences* 4(1):3-13.

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

McCabe, W.L. and J.C. Smith. 1976. *Unit Operations of Chemical Engineering*, 3rd ed. New York, NY: McGraw-Hill Book Company.

Mikki, M.S. 1986. Recent trends on the industrialization of dates in the Arab World with more emphasis on the status industry in Saudi Arabia. In *Proceedings of the Second Symposium on the Date Palm in Saudi Arabia*, 60-82. King Faisal University, Al-Hassa, Saudia Arabia. (In Arabic).

Murase, T., E. Iritani, J.H. Cho and M. Shirato. 1989. Determination of filtration characteristics of power-law non-Newtonian fluids-solids mixtures under constant-pressure conditions. *Journal of Chemical Engineering of Japan* 22(1):65-71.

Mustafa, A.I., A.M. Hamad, A.N. Wahdan and M.S. Al-Kahtani. 1982. Extraction of date syrup (Dibs) and its utilization in bakery products and juice. In *Proceedings of* *the First Symposium on the Date Palm in Saudi Arabia*, 534-543. King Faisal University, Al - Hassa, Saudia Arabia.

Peleg, Y. and R.C. Brown. 1976. Methods for evaluating the filterability of wine and similar fluids. *Journal of Food Science* 41:805-808.

Statgraphics. 1989. *Statistical graphics system*. Statistical Graphics Corporation, STSC, Inc., Rockville, MD.

Svarovsky, L. 1981. Filtration fundamentals. In *Solid-Liquid Separation*, 2nd ed, 242-258. London, UK: Butterworths.