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RHEOLOGICAL PROPERTIES OF MILK PROTEIN PRODUCTS PREPARED FROM BUFFALO'S MILK.

BY

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ABSTRACT

Rheological properties of freeze and oven dried rennet casein, lactic acid casein and total milk proteinate, prepared from buffalo's milk were measured in a rotational viscometer at various temperatures (30°C, 40°C and 50 °C) and at different protein concentrations (2, 5, 10 and 15 %), dissolved in alkali solution. Differences between shear stress values of ascending and descending curves were negligible and hence, no remarkable hysteresis was observed. Obtained shear stress values were found to be dependent on type, concentration and drying method of the tested casein. The maximum obtained shear stress values for 2% casein solution was 33-dynes/cm^2 at shear rate 1312 s^{-1} for freeze dried lactic acid casein and total milk proteinate. The obtained flow curves for the 2% casein solution, showed almost linear relationship between shear stress and shear rate values, which in turn express a Newtonian behaviour. Increasing the concentration of the casein solution to 5% did not greatly influence the obtained shear stress values as well as the linear characteristic of the obtained flow curves. Flow parameters (viscosity μ, consistency coefficient K and flow behaviour index n) were calculated according to Newtonian and non-Newtonian flow models and were given for all tested casein solutions. Also, activation energy of flow (Ea) was found to vary between 13.81 to 38.94 kJ/mol. Mathematical models of quadratic type were proposed to predict the viscosity values of casein solutions at different temperatures and concentrations. The obtained data are useful for designing of handling systems and for application of casein in food formulations.

Key words: Total milk proteinate, lactic acid casein , rennet casein, viscosity, and activation energy.

INTRODUCTION

Viscosity is one of the most important functional properties of food protein. It is important for providing physical stability to emulsion and other suspended particles in foods and contributes to the mouthfeel of foods directly and by controlling sugar crystal size in candy and confectionery products. The concentrations and inherent physicochemical properties, i.e. molecular weight, polydispersity, hydrophobicity, and conformation of each protein species, effect of the viscosity of the protein solution. The concentrations and physicochemical properties of other ionic and nonionic solutes also exert an important influence on the viscosity of protein solutions by contributing directly to viscosity and also by their tendency to interact and modify the physicochemical properties of the protein (Hall, 1996). Newtonian liquids are those that follow Newton's law, which postulate that viscosity is invariant over shear rate or stress. The viscosity of many liquids, however, is not constant over ranges of shear rates or stress. These non-Newtonian liquids can have a variety of flow profiles and flow curves, which can be described mathematically.

Viscosity is relevant from a food perspective for two reasons. First, it is an important functional property of foods, which is affected by concentration, shape, sizes and polydispersity of the tested biopolymer. This is industrially very important. Second, viscometric measurements on food biopolymers, either in highly purified form or in controlled mixtures of highly purified materials. allow us to probe fundamental molecular properties of the food macromolecule Hill, *et al.*, (1998). Additionally, both shear stress and apparent viscosity are a diminishing function of time of flow at particular shear rates, and material recovers part of its initial state after cessation of flow (partial thixotropy). According to Bastier, *et al.*, (1993) casein, which represent 80% of milk proteins,and their caseinate derivatives, are now used in dairy as well as non-dairy products. Casein and caseinates are widly used for their rheologically based functional properties. Fichtali, *et al.*, (1993) developed rheological model for caseinate dispersion, obtained from cow's milk, which would be useful to predict the range of shear, concentration and temperature suitable for preparation of casein dispersions with viscosities suitable for industrial handling and in processing operations. Studies on the rheological characteristics of buffalo's milk casein are scarce. Therefore, the objective of the present investigation was to prepare different types of casein from buffalo's milk and to study the effect of concentration and temperature on their rheological behaviour.

MATERIALS AND METHODS

Materials

Raw buffalo's milk was obtained from the herd of the Faculty of Agriculture, Ain Shams University, Cairo, Egypt.

Preparation of milk protein products:

Total milk proteinate, lactic acid casein and rennet casein were prepared according to the method described by Morr (1985). Total milk proteinate was prepared as follows: 10 kilograms of buffalo's skim milk were alkalined by 1 N NaOH to pH 10 and heated to 50 °C±1 to solubilize casein micelles. After that, pH was then adjusted to 3.5 at 40 °C to complex the whey protein and casein using 1 N HCl. Again the pH was raised to 4.6 by 1 N NaOH to precipitate the complexed protein. Coagulated proteins were removed from whey by using a cheese-cloth. The curd was washed three times with equal volumes of original milk by distilled water and warmed to 37 - 40 °C, then acidified to pH 4.6. The curd was pressed after the final wash and suspended in distilled water by addition of 1 N NaOH to bring the pH to 7.5. Rennet casein was prepared by adding 1 ml of rennet solution per 1 kg of skim milk at 37°C. After complete coagulation, cutting and whey drainage, the curd was treated as previously mentioned for Total milk proteinate. For preparation of lactic acid casein , raw skim milk was coagulated at pH 4.6 using lactic acid 2 N at 37 °C and the curd was treated as previously mentioned for total milk proteinate. Prepared protein samples were divided each in two portions. One portion was dried in oven at 60 °C for 6 hr, while the second portion was lyophilized at -40 °C by freeze drying system LYPH-LOCK-4.5. The moisture content of the dried samples ranged from 2 to 10%, while the protein content was in the range of 88 to 91%.

Rheological properties:

Milk protein products (Rennet casein, lactic acid casein and total milk proteinate) were dissolved in sodium hydroxide solution 2.5 N to give a final concentration of 2, 5, 10, 15 and 20 % (w/w). The rheological properties were measured using rotational coaxial viscometer (Rheotest II, Medingen, Germany) at temperatures 30°C, 40°C and 50°C. The rotaing double space devise (N) was used with fixed cup (S) of the viscometer. Shear stress data were recorded for shear rate values between 3 to 1312 sec^{-1} .The Newtonian viscosity (μ) as well as the parameters of non- Newtonian behaviour,(consistency coefficient, k and flow behaviour index, n) were calculated as given by Dail & Steffe (1990) and Toledo (1997):

$$\tau = \mu \, . \, \gamma \qquad (1)$$

and

$$\tau = \kappa \, . \, \gamma^{n} \qquad (2)$$

Where:

τ =Shear stress (Dynes/cm ^{2}), γ = Shear rate (s^{-1})

μ = Newtonian viscosity value (m Pa.s), n = Flow behaviour index

k = consistency coefficient (Dynes/cm ^{2} s^n).

Statistical analysis

SAS (1996) statistical computer program was applied. Correlation coefficient was also performed using the same program.

RESULTS AND DISCUSSION

Rheological characteristics:

The rheological characteristics of the tested buffalo's milk casein samples were discussed from the viewpoint of flow behaviour description of the casein solution, apparent viscosity values, flow parameters, effect of concentration and temperature of casein solution on the flow parameters as well as the activation energy of the viscosity. These parameters are of important for designing, handling and utilization of casein preparations.

Flow behaviour characteristics:

Figures (1, 2, 3 and 4) show the flow behaviour curves of the tested casein solutions of 2, 5, 10 and 15 % concentration, respectively. The flow behavior curves represent the relationship between shear stress values (τ) developed at shear rates (γ) ranging from 3 to 1312 s^{-1} , as described by Tang *et al.*, (1993).

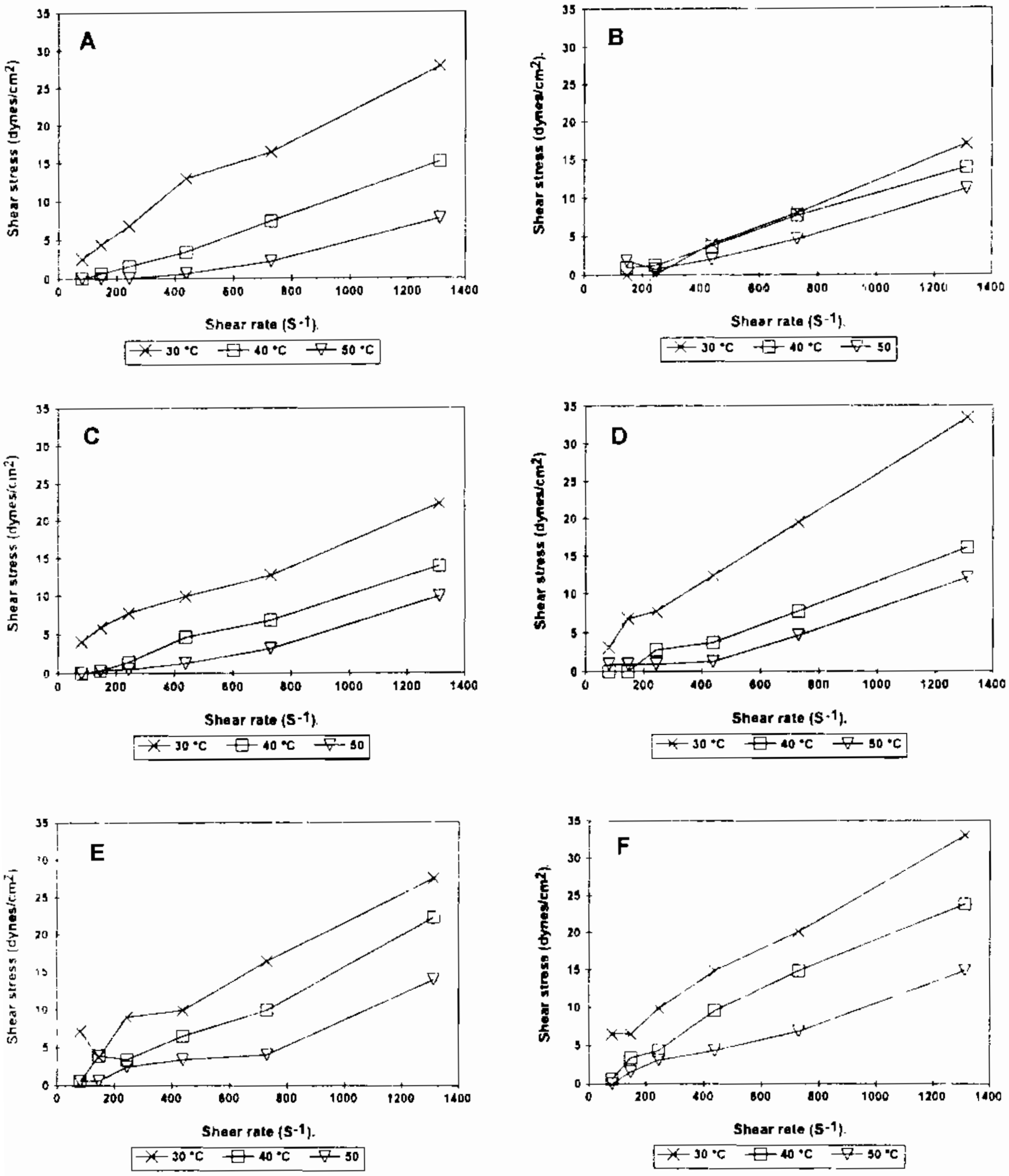

Fig.(1): Rheograms of 2 % casein solutions at different temperatures.
- Oven (A) and freeze dried (B) rennet casein.
- Oven (C) and freeze dried (D) lactic acid casein.
- Oven (E) and freeze dried (F) total milk proteinate.

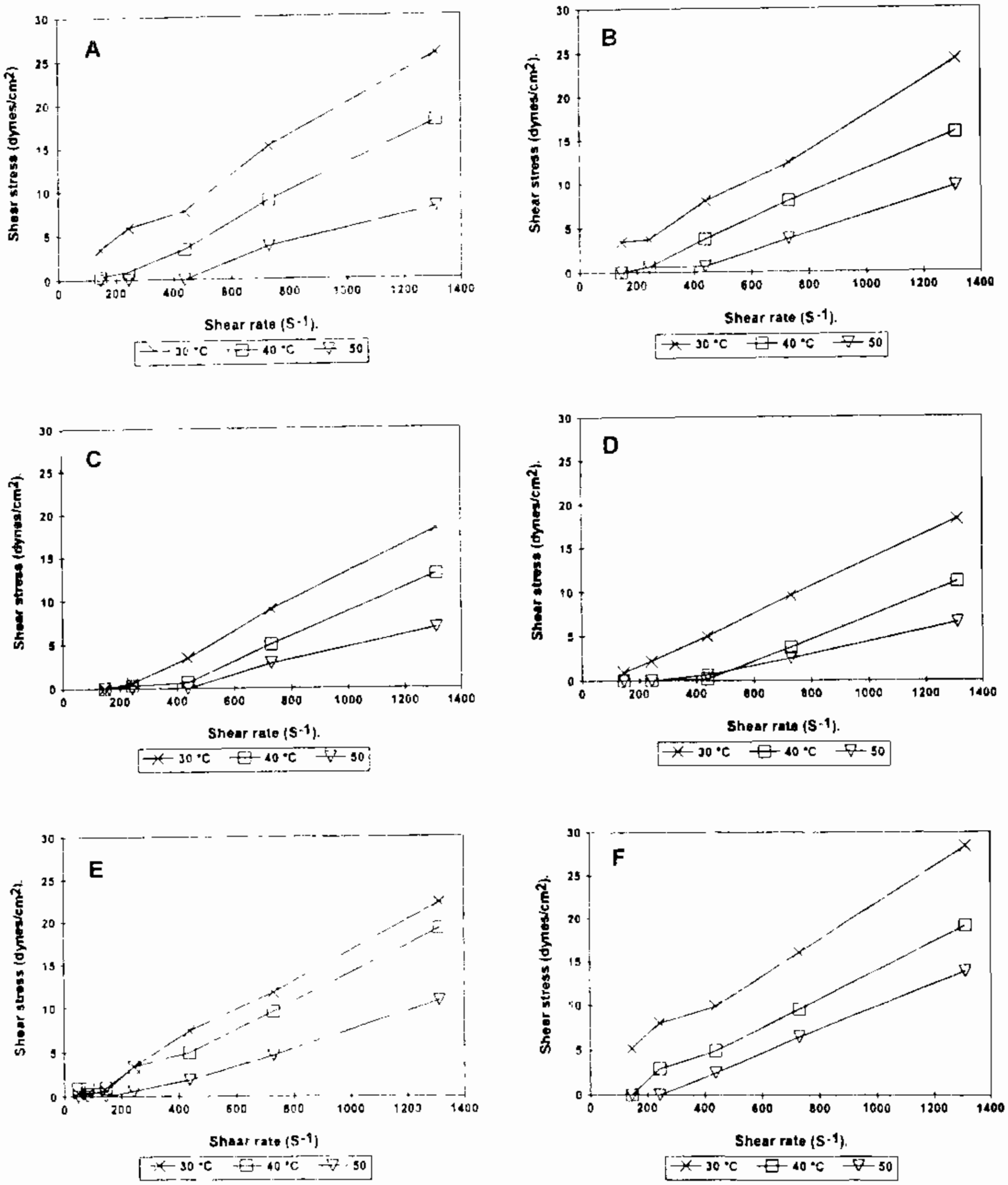

Fig.(2): Rheograms of 5 % casein solutions at different temperatures.
- Oven (A) and freeze dried (B) rennet casein.
- Oven (C) and freeze dried (D) lactic acid casein.
- Oven (E) and freeze dried (F) total milk proteinate.

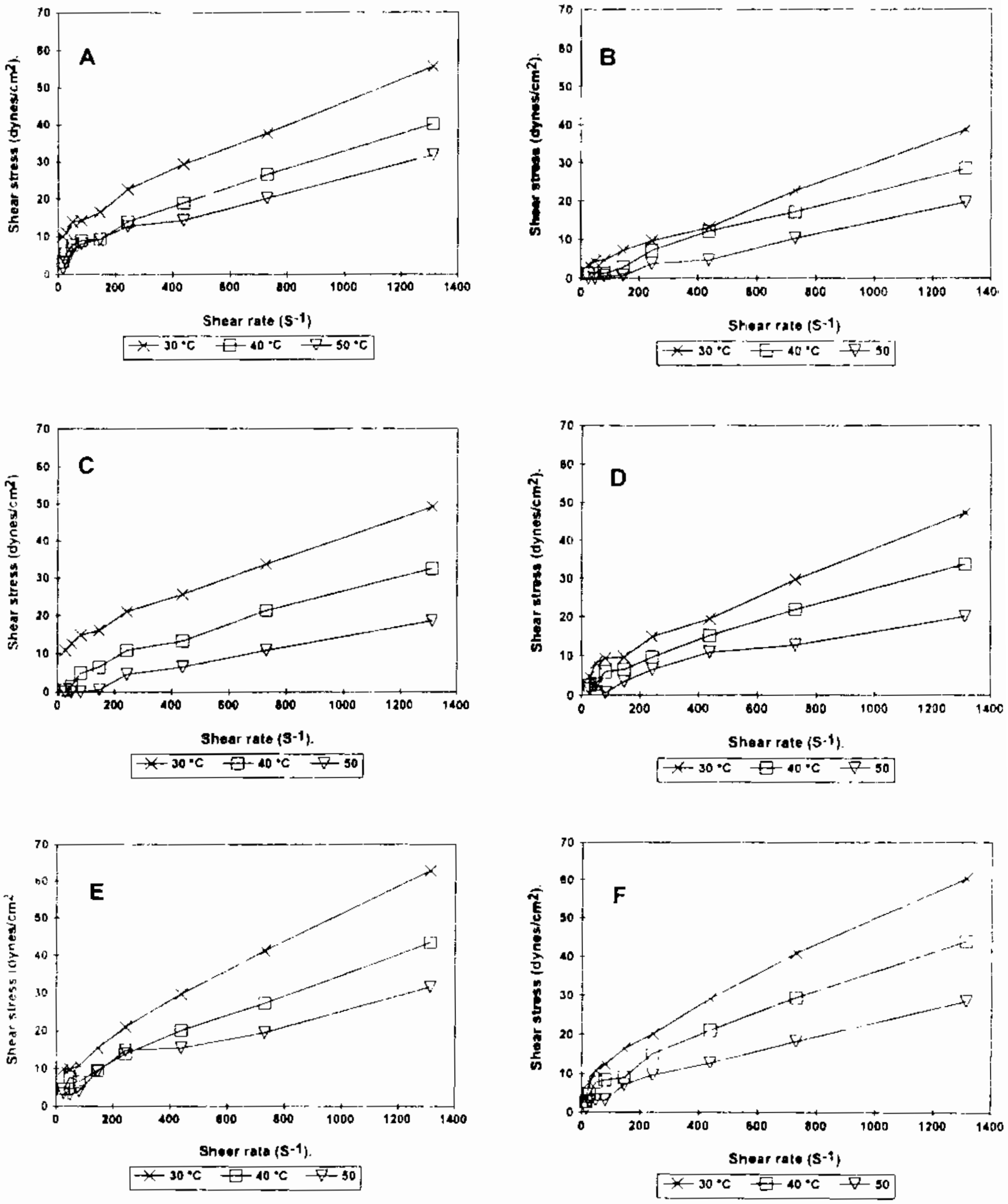

Fig.(3): Rheograms of 10 % casein solutions at different temperatures.
- Oven (A) and freeze dried (B) rennet casein.
- Oven (C) and freeze dried (D) lactic acid casein.
- Oven (E) and freeze dried (F) total milk proteinate.

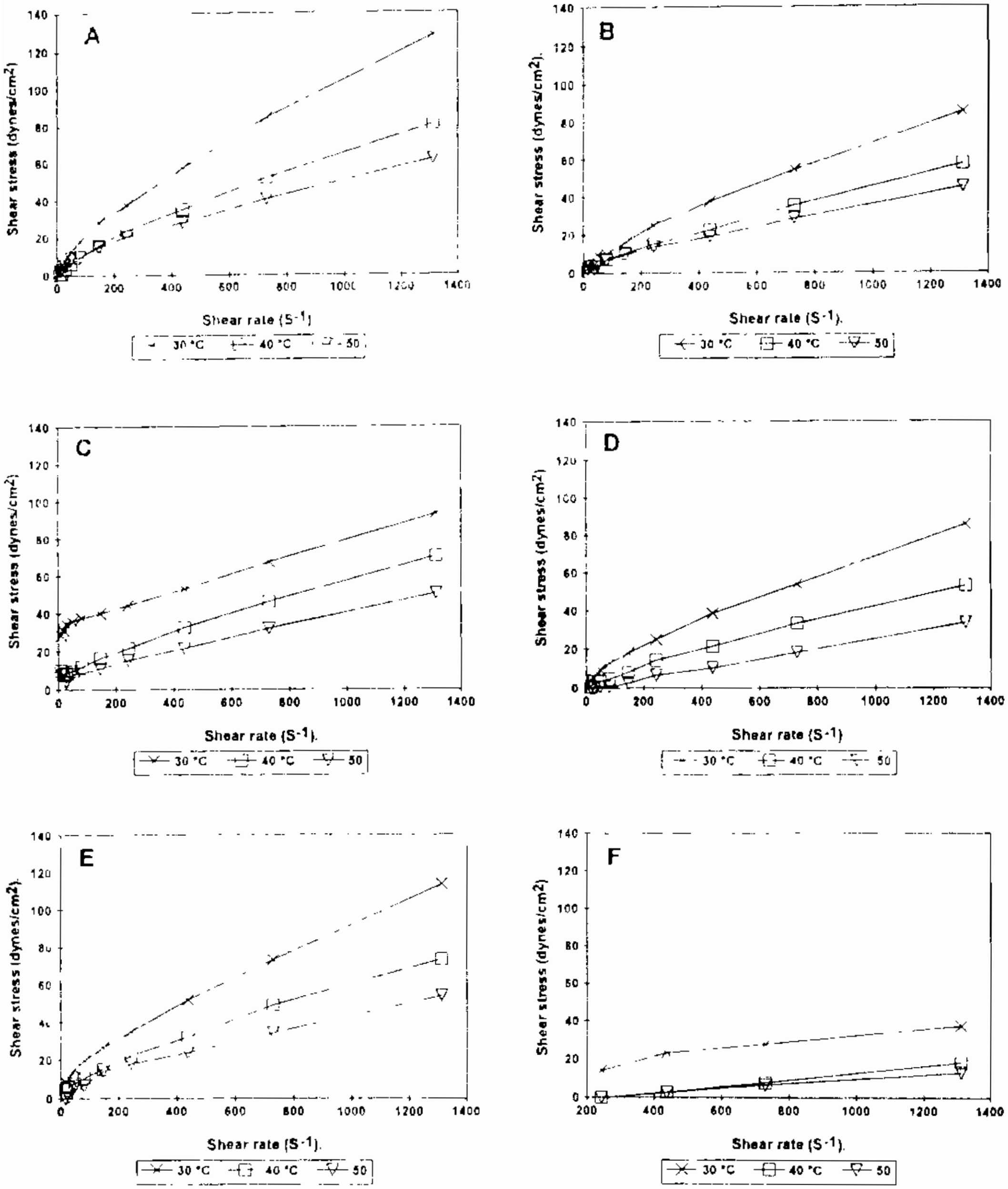

Fig.(4): Rheograms of 15 % casein solutions at different temperatures.
- Oven (A) and freeze dried (B) rennet casein.
- Oven (C) and freeze dried (D) lactic acid casein.
- Oven (E) and freeze dried (F) total milk proteinate

Differences between shear stress values of ascending and descending curves were negligible and hence, only ascending curves were considered in this study no remarkable hysteresis was observed.

It could be seen that the obtained shear stress values were dependent on type, concentration and drying method of the obtained protein. As seen in Fig. (1), the maximum obtained shear stress value for 2% casein solution was 33 dynes/cm^2 at shear rate 1312 s^{-1} for freeze dried lactic acid casein and total milk proteinate. For the 2 % casein solutions the shear stress response was only detectable at shear rate values higher than 27 s^{-1}. The obtained flow curves for the 2 % casein solution showed almost linear relationship between shear stress and shear rate values, which in turn express a Newtonian behaviour. As seen in Fig. (2), increasing the concentration of the casein solution to 5 % did not greatly influenced the level of the obtained shear stress values as well as the linear characteristic of the obtained flow curves. Such behavior of the 2 % and 5 % casein solutions could be referred to the absolute solubility of the casein powder in the high alkali medium used in this work. This lead, according to the polymer theory presented by Kulicke (1986), to the formation of thin solutions of the casein polymer with full hydration of the molecules and less interaction and interference between the hydrated molecules inside the casein solution. Such solution characteristics lead to a Newtonian flow behaviour. Increasing the casein solution to 10 % (Fig. 3) and 15 % (Fig. 4) lead to the appearance of intermolecular pulsation inside the solution resulting in an increase in the obtained shear stress response, which reached 65 dynes/cm^2 at shear rate 1312 s^{-1} for the 10 % solutions and corresponding values of 130 dynes/cm^2 for the 15 % solution. In the same time, the flow curves becomes less linear and showed tendency to non-Newtonian behavior. The shear stress response for the 10 and 15 % casein solutions was detectable at relatively low shear rate values (less than 27s^{-1}). As seen, shear stress values of the obtained casein solutions were increased by increasing casein concentration from 2 % to 15 %. Also, increasing the temperature from 30 °C to 50 °C decreased the shear stress values.

Generally, solutions of total milk proteinate showed higher shear stress response values than those of lactic acid and rennet caseins. Concerning the effect of the drying method of casein on its flow behavior characteristic, it could be noticed that oven dried samples showed higher shear stress response than those freeze dried samples, specially for solution with concentration higher than 5 %. The obtained results agree with those reported by Fichtali, *et al.*, (1993).

Flow parameters:

To predicate the type of the flow model dominating the flow behavior of the tested casein solution, the shear rate/shear stress data were evaluated according to the Newtonian (equation1) as well as the Ostwald (Power law, equation 2), and the obtained results are given in Tables 1, 2 and 3 for the tested solution of rennet, lactic acid casein and total milk proteinate, respectively. In each table, the flow parameters, viscosity (μ), consistency coefficient (K-value) and the flow behaviour index (n) were given as the result of the statistical analysis according to the two applied flow models (Newtonian and non-Newtonian) using

SAS statistical program. The R^2-value was given to determine the best-fit model. As seen, the R^2-values of the Newtonian plot of the tested samples were almost higher or close to those of the non-Newtonian plot, especially for protein concentrations 2, 5 and 10 %. For the protein concentration 15 %, the obtained R^2-values for the non-Newtonian behaviour were close to those of the Newtonian behaviour. From this point of view, solubilization of casein powder in high alkali medium gives complete soluble solution with flow characteristics close to the Newtonian behaviour, even at concentration 15 %.

Viscosity data given in Tables 1, 2 and 3 show that there is reflection point in the relationship between viscosity and concentration at 10 and 15% concentration, which is obvious in the curves given in Figure (5). Same trend was observed in the values of consistency coefficient (k value). Freeze dried sample of total milk proteinate and oven dried samples of rennet casein gave the highest viscosity values at all tested concentrations and temperatures, compared with that of the other tested samples. The reason could be refereed to the relatively higher moisture content of their dried protein samples (5-10 %), which in turn reflect the protection of protein from deformation during drying resulting in highly hydrating protein molecules giving corresponding high viscosity values. Data of the flow behaviour index (n-values) given in Table (1) show that the n-values was higher than 0.8 in most cases (very close to the unity), except in some cases at high concentrations, where the n-values were less than 0.8 showing a tendency of the tested casein solution to non-Newtonian behaviour.

Effect of temperature and concentration on the viscosity of casein solution:

As seen in (Tables 1, 2 and 3), viscosity values of the tested casein solutions were decreased by increasing temperature from 30 °C to 50 °C. The magnitude of this effect was dependent on type and concentration of the tested casein samples. The effect of temperature on the change in viscosity could be estimated from the value of the activation energy (Ea) as calculated from the Arrhenius equation (Toledo, 1997) as follows:

$$\mu = \mu_0 \,.\, \exp.^{Ea/RT} \qquad (3)$$

Where:

μ = Newtonian viscosity value (m Pa.s), μ_0 = constant, Ea = activation energy of flow (kJ /mol.), T= absolute tempreature (k) and R = gas constant.

The viscosity data given in Table 1, 2 and 3 were analyzed according to equation (3) and the results of the obtained activation energy values (Ea) are given in Table (4) Arrhenius equations was found to be suitable for presenting the dependence of viscosity of casein solutions on temperature, since the R^2-values were almost higher than 0.9. The activation energy values were in the range of 13.81 to 38.94 kJ /mol, which agree with the results given by Bastier, *et al.*, (1993) as well as Khalil and Metwally (1999). The highest (Ea)-value (38.44 kJ /mol) was obtained for 2% oven dried rennet casein solution, while the lowest value 13.81 was obtained for 15% oven dried lactic acid casein solution. However, there was no fixed trend in the obtained (Ea)-values with the concentration of the tested solutions.

Mathematical model for prediction of viscosity values of casein solutions:

As previously explained, viscosity of casein solutions was dependent on concentration and temperature. Therefore, a trial was carried out to find suitable equation for predication of viscosity at different temperatures and concentrations. The most suitable model found to adequately represent this relationship was a quadratic equation in the form:

$$\mu = \mu_0 \pm aC \pm bT \pm cC^2 \pm dT^2 \qquad (4)$$

Where:

μ_o - is a constant value of the viscosity; C is the concentration, T is the temperature in (°C) and a, b, c and d are constant coefficients, whose values are function of type of the casein solution, R^2-values for this mathematical model were found to vary between 0.908 and 0.971.

Table (1): Flow parameters of freeze and oven dried rennet casein prepared from buffalo's milk.

Temp.	Flow -Parameters		Protein concentration (%)			
			2	5	10	15
			Freeze dried rennet casein			
30 °C	**N**	μ	1.49	1.83	2.76	6.45
		R^2	0.999	0.995	0.996	0.981
	NN	K	1.39×10^{-3}	4.96×10^{-3}	0.409	0.443
		n	1.31	1.20	0.51	0.74
		R^2	0.999	0.948	0.965	0.977
40 °C	**N**	μ	1.15	1.41	2.15	4.33
		R^2	0.995	0.998	0.990	0.990
	NN	K	1.13×10^{-3}	1.31×10^{-3}	0.212	0.180
		n	1.32	1.88	0.64	0.804
		R^2	0.980	0.943	0.946	0.986
50 °C	**N**	μ	0.84	0.89	1.52	3.32
		R^2	0.930	0.967	0.989	0.984
	NN	K	0.026	4.28×10^{-4}	0.0112	0.158
		n	0.79	1.78	1.03	0.80
		R^2	0.785	0.883	0.976	0.979
			Oven dried rennet casein			
30 °C	**N**	μ	1.87	1.93	3.65	9.73
		R^2	0.984	0.994	0.974	0.978
	NN	K	0.057	0.018	3.994	2.871
		n	0.86	1.02	0.32	0.85
		R^2	0.992	0.956	0.956	0.946
40 °C	**N**	μ	1.26	1.55	2.82	6.17
		R^2	0.996	0.994	0.976	0.981
	NN	K	8.47×10^{4}	3.83×10^{-4}	0.97	0.10
		n	1.37	1.506	0.49	0.96
		R^2	0.996	0.981	0.983	0.964
50 °C	**N**	μ	0.83	0.95	2.23	4.58
		R^2	0.984	0.999	0.941	0.972
	NN	K	4.84×10^{-5}	3.45×10^{-4}	0.264	0.285
		n	1.67	1.31	0.69	0.77
		R^2	0.998	0.999	0.889	0.897

N = as Newtonian (Eq. 1) NN = as non- Newtonian (Eq. 2) μ= m Pa.s
K=dynes/cm2.Sce"

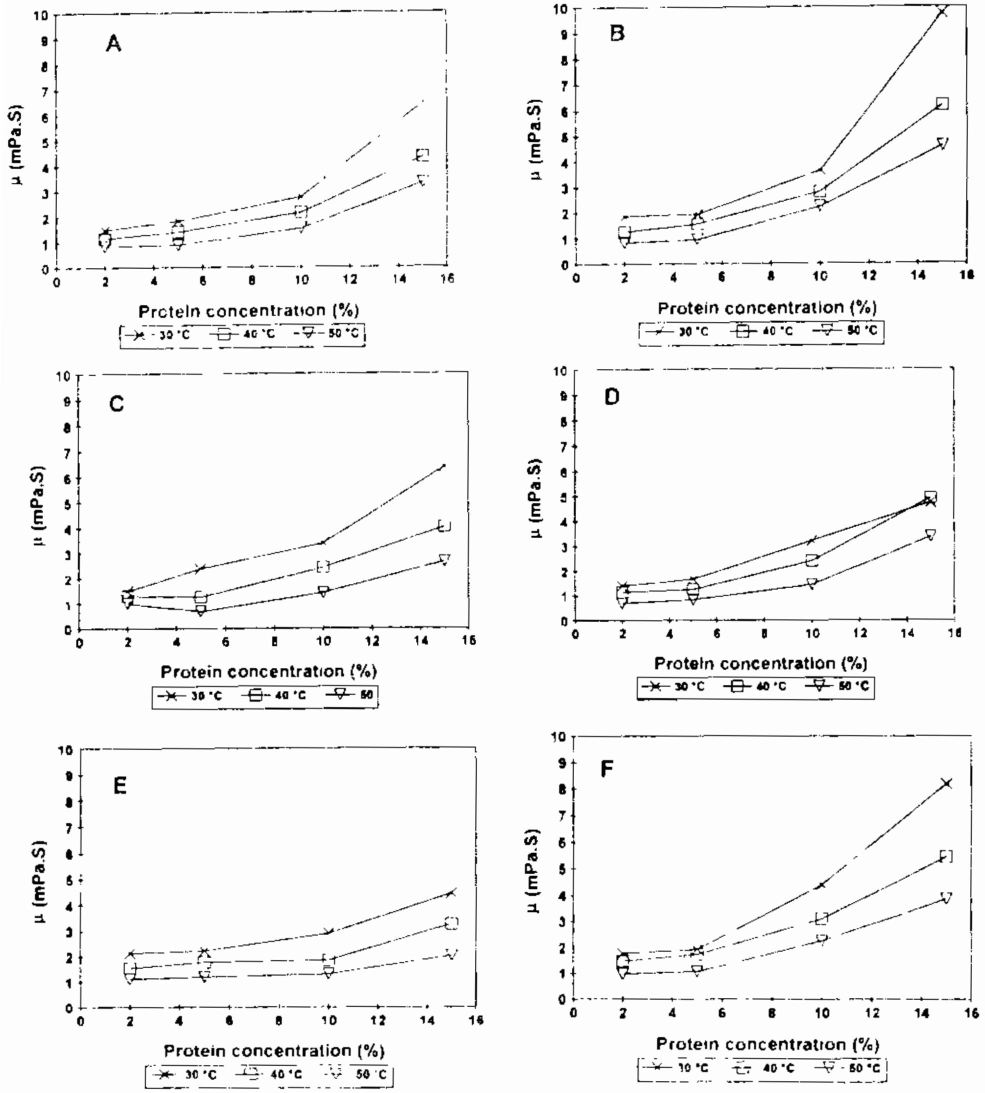

Fig. (5): Relationship between concentration and viscosity of milk proteins at different temperatures.

- Oven (A) and freeze dried (B) rennet casein.
- Oven (C) and freeze dried (D) lactic acid casein.
- Oven (E) and freeze dried (F) total milk proteinate.

Table (5) gives the constants of the proposed mathematical models for each type of the tested casein solutions. With the help of these constants the viscosity values could be predicted when applied in equations (4). According to, Fichtali, *et al.*, (1993), such mathematical models could applied within the tested concentration and temperatures for prediction of the viscosity of casein solutions.

Table (2): Flow parameters of freeze and oven dried lactic acid casein prepared from buffalo's milk.

Temp.	Parameters		Protein concentration (%)			
			2	5	10	15
			Freeze dried lactic acid casein			
30 °C	N	μ	1.49	2.38	3.38	6.37
		R^2	0.996	0.999	0.976	0.985
	NN	K	0.099	1.202×10^{-3}	0.297	0.773
		n	0.80	1.354	0.72	0 64
		R^2	0.980	0.994	0.951	0.990
40 °C	N	μ	1.25	1.29	2.42	4.02
		R^2	0.985	0.999	0.988	0.991
	NN	K	6.65×10^{-3}	1.62×10^{-5}	0.233	0.059
		n	1.07	1.87	0.68	0.97
		R^2	0.963	0.908	0.983	0.980
50 °C	N	μ	0.67	0.99	1.41	2.65
		R^2	0.948	0.999	0.966	0.997
	NN	K	1.314×10^{-3}	4.86×10^{-5}	0.187	2.308×10^{-3}
		n	1.22	1.64	0.64	1.36
		R^2	0.864	0.979	0.969	0.957
			Oven dried lactic acid casein			
30 °C	N	μ	1.39	1.66	3.21	4.73
		R^2	0.988	0.998	0.941	0.993
	NN	K	0.320	3.47×10^{-4}	2.104	17.496
		n	0.57	1.52	0.42	0.19
		R^2	0.982	0.999	0.950	0.864
40 °C	N	μ	1.14	1.25	2.40	4.91
		R^2	0.992	0.975	0.973	0.994
	NN	K	1.125×10^{-4}	9.73×10^{-5}	0.043	2.812
		n	1.67	1.64	0.95	0.39
		R^2	0.942	0.999	0.938	0.853
50 °C	N	μ	0.68	0.83	1.44	3.35
		R^2	0.952	0.999	0.980	0.998
	NN	K	7.924×10^{-5}	1.12×10^{-4}	1.172×10^{-3}	2.971
		n	1.61	1.52	1.38	0.33
		R^2	0.982	0.998	0.856	0.845

N = as Newtonian (Eq. 1) NN = as non- Newtonian (Eq. 2) μ= m Pa
K=dynes/cm2.Sce^n

Table (3): Flow parameters of freeze and oven dried total milk proteinate prepared from buffalo's milk.

Temp.	Parameters		Protein concentration (%)			
			2	5	10	15
			Freeze dried total milk proteinate			
30 °C	N	μ	2.11	2.21	2.88	4.46
		R^2	0.995	0.989	0.956	0.897
	NN	K	0.181	0.141	0.436	0.053
		n	0.72	0.69	0.71	0.954
		R^2	0.996	0.919	0.954	0.925
40 °C	N	μ	1.54	1.77	1.85	3.26
		R^2	0.987	0.995	0.966	0.999
	NN	K	$4.912\text{x}10^{-3}$	$5.910\text{x}10^{-3}$	0.469	$5.07\text{x}10^{-4}$
		n	1.21	1.12	0.63	1.46
		R^2	0.930	0.993	0.985	0.991
50 °C	N	μ	1.10	1.18	1.30	2.02
		R^2	0.982	0.999	0.978	0.997
	NN	K	0.0131	$1.914\text{x}10^{-4}$	0.197	$2.872\text{x}10^{-4}$
		n	0.96	1.56	0.69	1.50
		R^2	0.981	0.988	0.965	0.982
			Oven dried total milk proteinate			
30 °C	N	μ	1.77	1.92	4.40	8.18
		R^2	0.980	0.995	0.985	0.987
	NN	K	0.067	$1.139\text{x}10^{-3}$	2.261	2.227
		n	0.83	1.39	0.42	0.51
		R^2	0.944	0.952	0.954	0.979
40 °C	N	μ	1.47	1.72	3.11	5.45
		R^2	0.988	0.989	0.979	0.987
	NN	K	$2.842\text{x}10^{-3}$	0.019	0.632	1.249
		n	1.25	0.92	0.57	0.52
		R^2	0.988	0.907	0.983	0.949
50 °C	N	μ	0.97	1.06	2.25	3.87
		R^2	0.916	0.994	0.919	0.968
	NN	K	$1.892\text{x}10^{-3}$	$4.43\text{x}10^{-4}$	6.553	0.040
		n	1.22	1.44	0.76	1.05
		R^2	0.903	0.996	0.945	0.895

N = as Newtonian (Eq. 1) NN = as non- Newtonian (Eq. 2) μ= m Pa.s
K=dynes/cm2.Sce^n

Table (4): Activation energy (E_a; KJ/mol) values of different preparations of buffalo's protein solutions.

Parameters	2	5	10	15
Freeze dried rennet casein				
μ_o	1.5×10^{-4}	1.7×10^{-5}	1.9×10^{-4}	1.4×10^{-4}
Ea	23.28	29.74	24.22	27.07
R^2	0.9945	0.9728	0.9875	0.9907
Freeze dried lactic acid casein				
μ_o	4.0×10^{-6}	1.5×10^{-6}	6.1×10^{-6}	1.4×10^{-4}
Ea	32.58	35.82	35.48	32.76
R^2	0.8919	0.9579	0.9797	0.9958
Freeze dried total milk proteinate				
μ_o	6.3×10^{-5}	1.1×10^{-4}	6.9×10^{-6}	1.4×10^{-5}
Ea	26.31	25.06	32.57	31.54
R^2	0.9994	0.9342	0.9875	0.9818
Oven dried rennet casein				
μ_o	3.9×10^{-7}	1.5×10^{-6}	1.3×10^{-3}	8.5×10^{-6}
Ea	38.94	35.80	20.05	35.17
R^2	0.9933	0.9339	0.9999	0.9998
Oven dried lactic acid casein				
μ_o	3.9×10^{-7}	1.4×10^{-6}	1.3×10^{-3}	8.5×10^{-6}
Ea	28.06	29.86	32.51	13.81
R^2	0.9324	0.9803	0.9695	0.6522
Oven dried total milk proteinate				
μ_o	1.1×10^{-4}	1.5×10^{-4}	8.7×10^{-5}	4.8×10^{-5}
Ea	24.59	23.99	27.29	30.32
R^2	0.9486	0.8644	1.0000	0.9992

μ_o = (m Pa.s) Ea = KJ/mol

Table (5): Constant parameters for viscosity predication models.

Type of protein	Constant μ_o	Constants coefficients of predication equation				R^2
		a	b	c	d	
Freeze dried						
Rennet casein	5.28	-0.232	-0.105	0.030	0.0003	0.9393
Lactic acid casein	7.75	-0.026	-0.235	0.016	0.0017	0.9082
Total milk proteinate	7.88	-0.274	-0.175	0.024	0.0008	0.9085
Oven dried						
Rennet casein	10.30	-0.330	-0.322	0.044	0.0027	0.9121
Lactic acid casein	-0.508	-0.065	0.149	0.019	-0.0026	0.9707
Total milk proteinate	7.18	-0.058	-0.193	0.024	0.0011	0.9137

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الخواص الريولوجية لمنتجات بروتينية محضرة من اللبن الجاموسى

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يهدف هذا البحث الى دراسة بعض الخواص الريولوجية لمنتجات بروتينية مثل بروتينات اللبن الكلية والكازين اللاكتيكي وكازين المنفحة التى تم تحضيرها من اللبن الجاموسي والمجففة بالفرن أو باستخدام طريقة التجفيد. وقد تم تجهيز محاليل من هذه المنتجات البروتينية بتركيزات من ٢، ٥، ١٠و ١٥ % فى محلول هيدروكسيد صوديوم ٠,٢عيارى ثم تم تقدير الخواص الريولوجية لهذة المحاليل باستخدام جهاز تقدير اللزوجة الاسطوانى الدورانى عند معدلات قص من ٣ الى ١٣١٢ لكل ثانية وعلى درجات حرارة من ٣٠ الى ٥٠ °م.

ولقد أوضحت النتائج الريولوجية أن الفروق بين قيم الإجهاد لمنحنى الصاعد والهابط (وهى قيم معبرة عن مقدار الإنهيار التركيبى نتيجة للقص) ليست ذات تأثير معنوى.

كما أظهرت النتائج أن قيم الإجهاد تعتمد على تركيز ونوع وطريقة تجفيف الكازين ووجد أن أعلى قيم قص (إنزلاق) لمحلول ٢ % من بروتينات اللبن الكلية وكذلك الكازين اللاكتيكى كانت ٣٣ داين/سم^{٢} .

كما وجد أن منحنيات السريان (التدفق) المتحصل عليها من محلول ٢ % كازين لها علاقة خطية لمعدلات القص والإجهاد، لذلك يمكن القول بأن محلول ٢ % كازين يسلك سلوك السوائل النيوتينية.

وقد دلت النتائج المتحصل عليها أن زيادة تركيز المحلول الى ٥ % لم يكن له تأثير على قيم معدلات الإجهاد وكذلك على العلاقة الخطية المتحصل عليها من منحنيات السريان، بالإضافة الى ذلك فإن قيم الطاقة التنشيطية تتراوح بين ١٣,٨١ الى ٣٨,٩٤ كيلو جول/مول.

وقد تم إقتراح معادلات رياضية لقيم اللزوجة لمحاليل البروتينات المحضرة عند درجات مختلفة من الحرارة والتركيز ، ومن هذة النتائج المتحصل عليها تتضح أهمية الخواص الريولوجية لمحاليل الكازين المختلفة للحصول على الثوابت والمعادلات التى يمكن الإستفادة منها فى تصميم عمليات تداول وتراكيب الأغذية.