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Rheological Properties of Tomato Concentrate

Manish Dak, Radha Charan Verma, and S N A Jaaffrey

Abstract

Rheological properties of tomato concentrate were evaluated using a wide-gap rotational viscometer (Brookfield Engineering Laboratories: Model LVDV-II) at different temperatures of 20, 30, 40, 50, and 60^{O}C, at concentration of 18, 12.18 and 8.04 % total solids, and at appropriate shear rate(1-100 RPM). The power law model was fitted to the experimental results. The values of flow behaviour index (n) were found less than unity (0.23 to 0.82) at all the temperature and the concentration indicating shear-thinning (pseudoplasticity) behaviour of the concentrate. The correlation between the observed consistency coefficient ranging from 0.09 to 65.87 Pa.sn and the inverse absolute temperature has been exhibited by Arrhenius model. Consistency coefficient increased exponentially with increase in the concentration. Statistical model was used for prediction of the consistency coefficient as a function of temperature and concentration which showed a good agreement (r2=0.99) between experimental and theoretical values. The magnitude of activation energy were found to be in the range of 8.6 to 14.08 kJ/mol.K.

KEYWORDS: apparent viscosity, shear rate, rheology, pseudoplastic, power law model, flow behaviour index, consistency coefficient, activation energy, hot-break extracted

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1. Introduction

Rheology is the science of deformation and flow behaviour of the matter. The consistency of a Newtonian fluid like water, milk or clear fruit juice can be characterize by term viscosity.Viscosity of some non-Newtonian fluids changes with varying shear rates and hence should be characterized by more than one parameters. Viscosity of some non-Newtonian fluids do not change with duration of shear rate (such fluids are called time-indepent non-Newtonian fluids) and be represented by power law model in terms of spindle speed(Rizvi and Mittal, 1997) using wide-gap rotational viscometer.

$$\mu_a = K\,(1/n)^{n}\,(4\,\pi\,N)^{n-1}$$

or, $$\ln(\mu_a) = (n-1)\ln(4\pi N) + \ln(K) - n\ln(n) \quad \text{.................... (1)}$$

Where,

μ_a	=	Apparent viscosity (Pa.s)
N	=	Spindle speed (RPS)
K	=	Consistency coefficient (Pa.s^n)
n	=	flow behaviour index (dimensionless)

Knowledge of rheological properties of fluid foods are useful for process engineering application , equipment design (heat exchanger ,evaporator and agitator), designing of transport system, deciding pump capacity and power requirement for mixing. Moreover the derived results of flow properties of foods as determined for the number of purposes such as quality control, understanding the structure and correlation with sensory evaluation (Rao and Anantheswaran, 1982; Ilicali, 1985; Dodeja et al., 1990; Leong and Yeow 2002).

Fluid foods are subjected to a variety of shear rate (RPM), different temperature and concentration during processing operations.Hence, their rheological properties are studied as a function of shear rate, temperature and concentration. The effect of temperature on the apparent viscosity or consistency coefficient at a specific shear rate is generally expressed by Arrhenius type relationship (Vitali and Rao, 1984; Speers and Tung, 1986).

$$K = A_0\ \exp\left(E_a / (R\,T)\right) \quad \text{....... (2)}$$

Where,

A_o	=	Constant
E_a	=	Activation energy of flow (kJ/mol.K)
R	=	Universal Gas constant (8.314 J/mol.K)
T	=	Absolute temperature (K)

The effect of concentration on apparent viscosity or consistency coefficient is generally described by an exponential type relationship (Cervone and Harper, 1978; Vitali and Rao, 1984).

$$K = a e^{bx} \qquad .... (3)$$

Where a and b are constants, x is concentration.

Velez and Barbosa (1997) combined the effect of temperature and concentration on consistency coefficient into a single logarithmic model as represented in equation (4).

$$\ln K = \beta o + \beta_1 (1/T) + \beta_2 X \qquad ..... (4)$$

Where β_o, β_1 and β_2 are constants.

Tomato (*Lycopersicum esculentum*) is one of the most important fruit for industrial processing of juice. Thoroughly ripe tomatoes of intense or bright red colour as well as other factors such as high yield, high content of total solids, good and characteristics flavour and high sugar content with fairly low acidity are required for processing. Large quantities of tomatoes are canned or made into paste, puree, juice, ketchup and sauces. Tomato is a good source of potassium, β-carotene (vitamin-A) and vitamin-C. It is very important for weight reducing diets (Bielig and Werner, 1986).

Rheological properties of fruit concentrate appears to be very much dependent of their varieties, method of juice extraction (e.g. cold-break or hot-break), concentration of juice/ pulp, climatic and seasonal variation (winter or summer).Therefore the present investigation was undertaken to study the rheological properties of tomato concentrate as a function of temperature and concentration.

2. Materials and methods

2.1 *Sample preparation*

Fully ripe and red " F1 hybrid" variety of tomatoes were procured from local market during the month of April (summer season) . After washing and sorting juice was extracted by hot-break extraction method (heating in boiling water for 2-5 min to soften before extraction of juice) in mixer and grinder. The juice was filtered using 40 mesh type filter and concentrated in freeze drier(Khera Instruments Ltd.,New Delhi : Model : KI 251: Capacity 6 kg) at vacuum approx.

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0.02 mm of Hg. to a concentration of 20 % total solid and immediately stored in refrigerator at 4°C till used. The sample of various concentration 18, 12.18, and 8.04% total solids used in present investigation were prepared by reconstituting the concentrate with water. The samples were chemically characterized for %total solid, ^{0}brix, pectin and titrable acidity(Ranganna, 1997) as given in Table1.

2.2 *Rheological measurements and analysis*

Rheological properties were measured using Brookfield Viscometer (Brookfield Engineering Laboratories : Model LVDV-II). A sample of 500 ml of tomato concentrate was used in a glass beaker of 600 ml size for all the experiments. The sample was placed in temperature controlled water bath(Cintex industrial corporation, Dadar, India) to bring it at various desired temperature(20,30,40,50 and 60^{0}C). The measurement range of LVDV-II Brookfield Viscometer between 10 to 100% full scale torque was adjusted by selection of specific spindle (S-61; S-62; S-63; S-64) and its rotational speed (1 to 100 RPM) for the various concentrate.

Data were analysed using power law model (Eq.1) and dependence of rheological properties (consistency coefficient) on temperature and concentration were evaluated fitting Arrhenius model (Eq.2) and exponential equation (Eq.3) respectively with the help of MS-Excel software.

3. Results and Discussions

The values of ln (μ_a) was plotted against ln ($4\pi N$) (Eq.1) and fitted a straight line with negative slope (Fig. 1 for 18 % total solid concentration) at temperature 20 to 60°C. It is inferred from Fig. 1 that the negative slope of straight line (Eq.1) shows the non-Newtonian/shear-thinning nature of tomato concentrate.Similar results were reported for mango juice by Dak et al.,2006. The flow behaviour index (n) and consistency coefficient (K) were calculated from slope and intercept of straight line are given in Table 2 for various concentration 18, 12.18, and 8.04 % TS.

Table 1

Chemical composition of tomato concentrate

Constituent	Samples		
	1	2	3
% Total solids	8.04	12.38	18
° Brix (TSS)	6	10	16
Pectin as calcium pectate (mg/100 g)	0.6	0.9	1.3
Titrable acidity as citric acid (%)	0.4	0.67	1.2

It is evident that the values of flow behaviour index (n) (Table 2) are less than 1 for all cases which showed pseudoplastic nature of tomato concentrate.Statistical analyis(ANOVA at 1% level of significance) indicated that there is no appreciable effect of temperature on flow behaviour index(Molwane and Gunjal,1985 ; Torgul and Arslan,2004 ; Dak et al.,2006).

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Table 2

Variation in flow behaviour index (n) and consistency coefficient (K) of tomato concentrate with temperature and concentration

Parameters	Temperature (°C)	Concentration (% total solids)		
		8.04	12.18	18
n	20	0.78	0.49	0.23
K		0.26	2.73	65.87
n	30	0.64	0.52	0.26
K		0.22	1.99	56.14
n	40	0.67	0.53	0.26
K		0.19	1.65	48.48
n	50	0.82	0.51	0.26
K		0.18	1.52	43.58
n	60	0.74	0.53	0.35
K		0.17	1.32	33.41

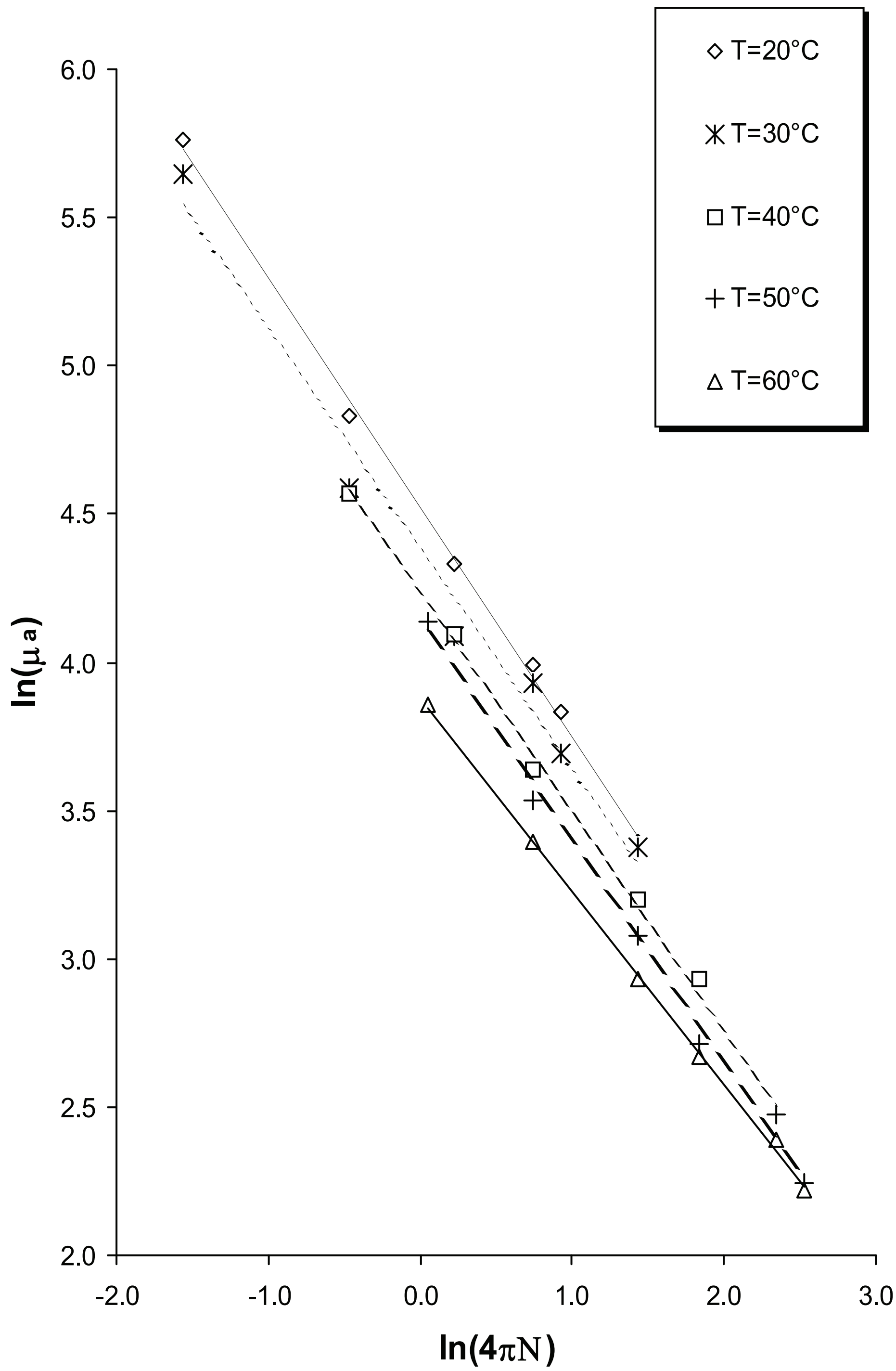

Fig.1: Flow curves of tomato juice concentrate at 18% TS concentration

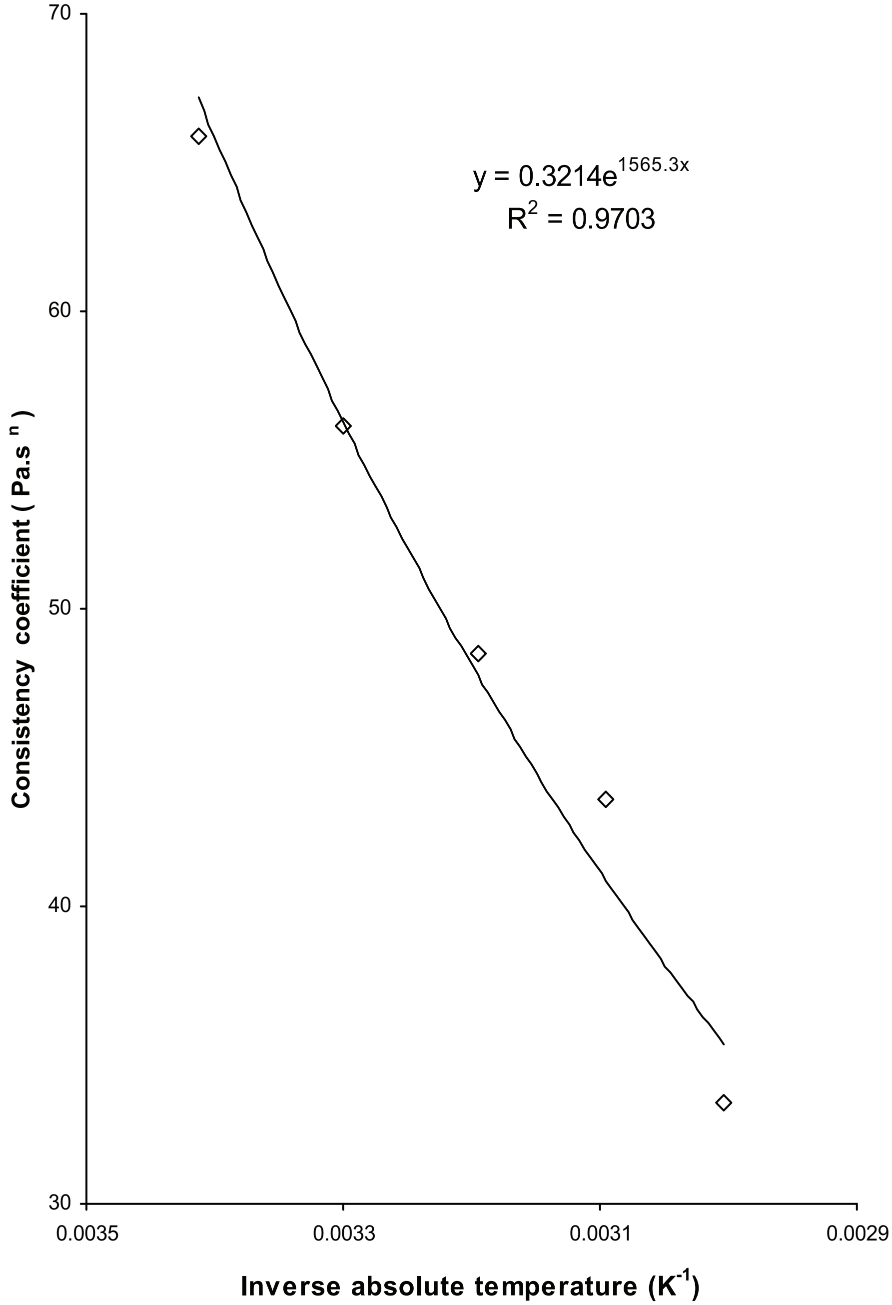

Fig. 2 : Arrhenius curve of tomato concentrate at 18 % TS concentration

On the other hand consistency coefficient varies appreciably with temperature and concentration (Table 2). Fig. 2 shows sample plot of consistency coefficient against the inverse of absolute temperature (1/T) for concentration of 18% total solid of tomato concentrate and these data have been fitted using equation (2) (Table 3). It showed positive correlation between consistency coefficient (K) and inverse absolute temperature (1/T) for all concentrations(Table 2).The activation energy of flow varying from 8.6 to 14.08 kJ/mol.K are found in good agreement with reported values for fluid foods (Rao et al., 1981).

Table 3
Activation energy of flow of tomato concentrate

Concentration (% total solid)	A_o	Activation energy, E_a (kJ/mol.k)	r^2
18	0.32	13.01	0.97
12.18	0.008	14.08	0.96
8.04	0.007	8.6	0.95

Fig. 3 shows a plot of consistency coefficient v/s concentration and these data have been fitted using exponential relationship (3) (Table 4), it showed that consistency coefficient increases exponentially with increase in concentration at given specified temperature (20, 30, 40, 50, and 60°C). These results are consistent with earlier reported studies for other fruit juices (Vitali & Rao, 1984; Khandari et al., 2002).

The effect of both variables (temperature and concentration) on consistency coefficient of tomato concentrate is combined into single logarithmic (Eq. 4) model.

The data were fitted in Statistical model (4) and represented in equation (5).

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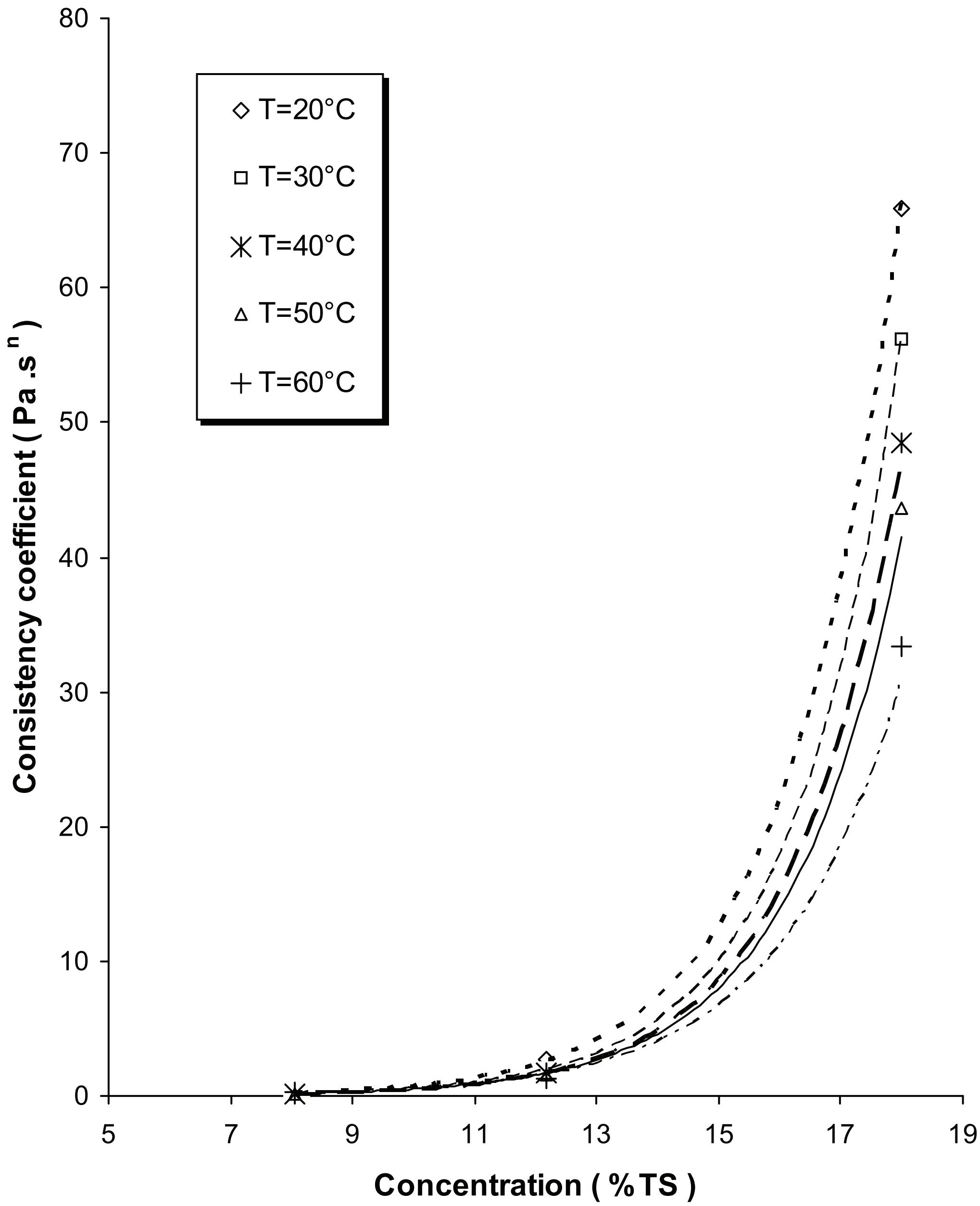

Fig. 3 : Effect of total solids concentration on consistency coefficient of tomato concentrate

$$\ln K = -6.717 + 15.984\,(1/T) + 0.563\,X \qquad \text{.....}\ (5)$$

Using Eq. (5), consistency coefficients were predicted as a function of temperature and concentration (Table 5).

Figure (4) shows the three -dimensional behaviour of consistency coefficient as a function of temperature and concentration. The effect of these two variables are opposite because solid concentration causes an increase in consistency coefficient and temperature diminishes it (Khandari et al. 2002).

Table 4

Derived results of exponential relationship $k = ae^{bx}$ for tomato concentrate

Temperature (°C)	a	b	r^2
20	3.1 E -03	0.56	0.99
30	1.8 E -03	0.58	1.0
40	1.7 E -03	0.57	0.99
50	2.2 E -03	0.55	0.99
60	3.3 E-02	0.51	0.99

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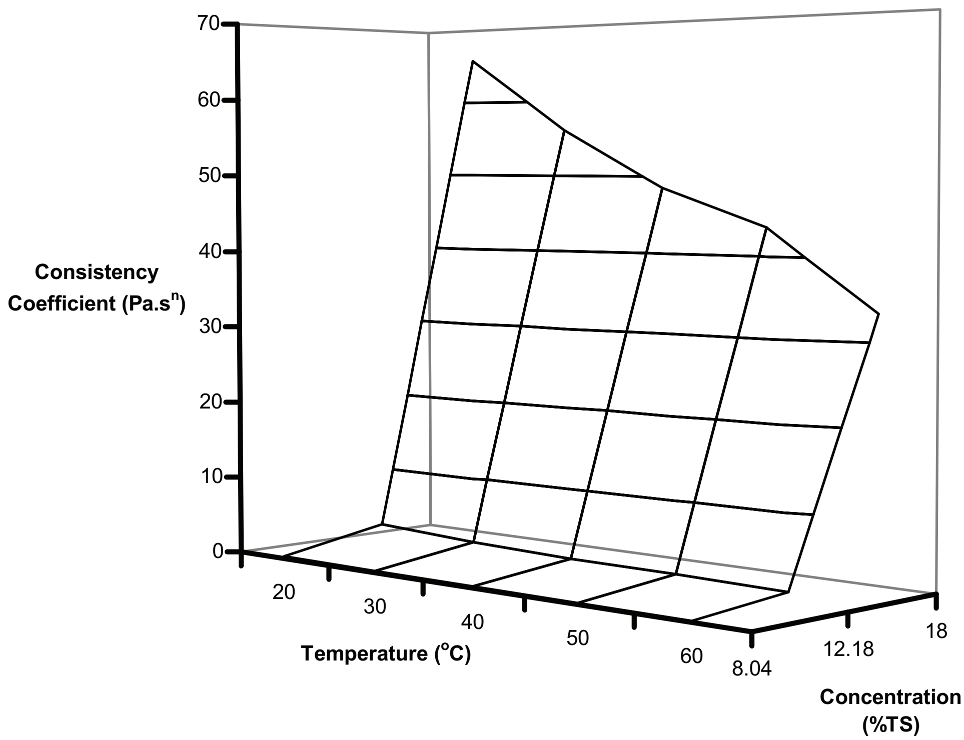

Fig.4 : Combined effect of temperature and concentration on consistency coefficient

As the temperature was lowered the consistency coefficient increased and the highest consistency coefficient was observed at lower temperature and highest total solids content. It indicated that as the total solid concentration increases and temperature decreases more energy would be required in pumping and mixing in unit operations.

Table 5

Predicted values of consistency coefficients

Temperature (°C)	Concentration (% total solids)		
	8.04	12.18	18
20	0.25	2.56	67.78
30	0.19	1.96	51.92
40	0.17	1.72	45.45
50	0.16	1.58	41.96
60	0.15	1.5	39.78

Fig.5 indicated that there was a good agreement(r^2=0.99) between experimental and theoretical values of consistency coefficient predicted by models (5).

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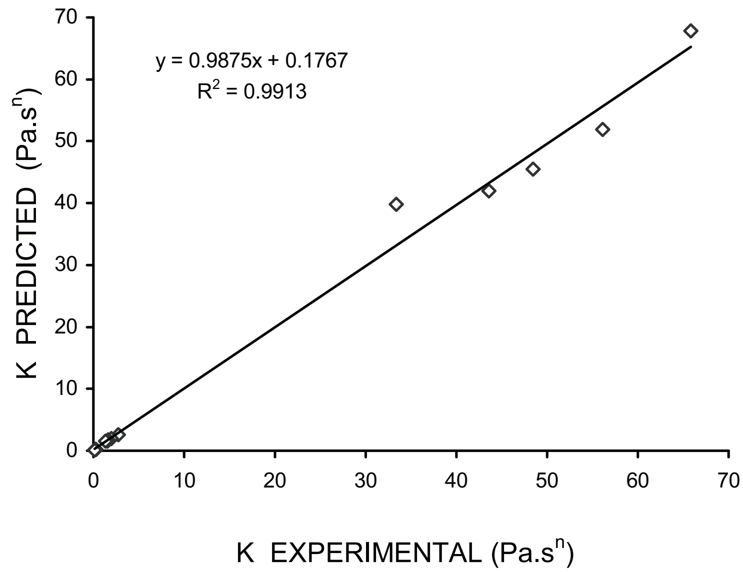

Fig. 5 : Plots for predicted v/s experimental value of consistency coefficient

Apparent viscosity depends upon shear rate(Table 6) and its values for shear rate are shown in Fig.6 for two concentrations 18 and 12.18 % total solids at 50°C temperature. It is observed that for the entire range of concentration under study with increased shear rate, the apparent viscosity decreased. It is also observed that apparent viscosity decreases at a faster rate from 62.62 to 9.45 Pa.s for higher concentration (18 %TS) than from 1.52 to 0.49 Pa.s at low concentration(12.18 % TS) (Molwane and Gunjal, 1985,Dak et al., 2006).

Table 6

Variation in apparent viscosity (Pa.s) of tomato concentrate with shear rate (RPM) at 50 °C

Shear rate (RPM)	Concentration (% total solids)		
	8.04	12.18	18
5	-	-	62.62 ± 1.57
10	-	1.52±0.06	34.24 ± 1.085
20	-	1.05±0.02	21.7±0.23
30	0.14±0.002	0.84±0.021	15.08±0.15
50	0.12±0.0027	0.67±0.012	11.9 ± 0.1
60	0.107±0.0017	0.6±0.00005	9.45±0.14
100	0.095±0.00047	0.49±0.01	-

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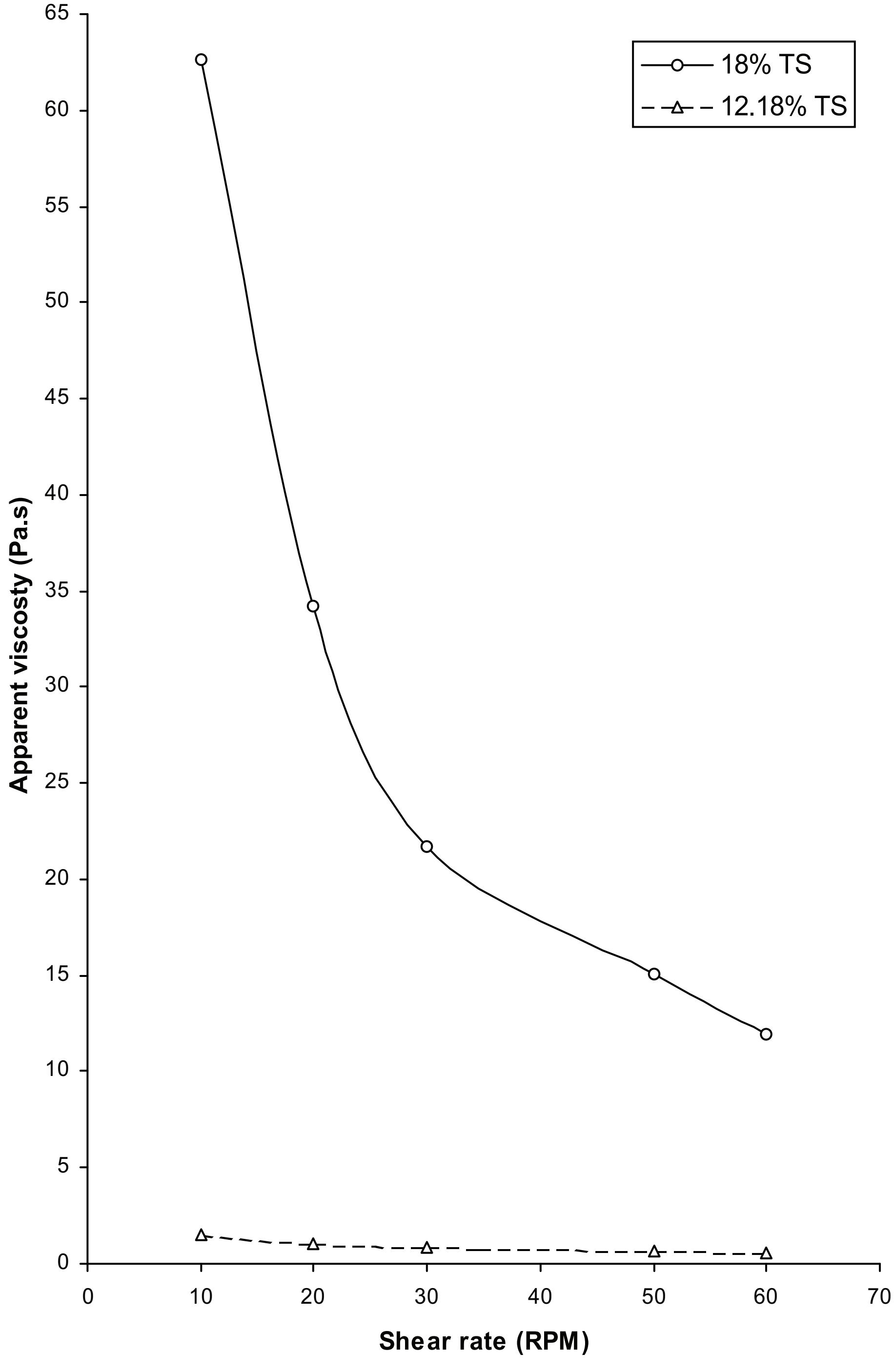

Fig.6 : Variation in apparent viscosity of tomato concentrate with shear rate at 50°C

4. Conclusions

Consistency coefficient shows positive correlation (0.09 to 65.87 Pa.s^n) with inverse absolute temperature (20 to 60 ^{0}C) and it also increases exponentially with increase in concentration(8.04 to 18 %TS). Apparent viscosity decreased at a faster rate from 62.62 to 9.45 Pa.s for higher concentration than from 0.14 to 0.095 Pa.s at low concentration as a function of ascending shear rate (1 to 100 RPM). Flow behaviour index was less than unity (0.23 to 0.82) revealing shear-thinning/pseudoplastic nature of tomato concentrate in all cases.

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