International Journal of Biological, Life and Agricultural Sciences
ISSN: 2415-6612
Vol:4, No:2, 2010

Time Independent Behavior of Tomato Paste

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***Abstract*—**This paper deals with rheological behavior of tomato paste from the view point of time independent properties inclusive of processing variables such as sample temperature which influence on rheological properties as well as breaking temperature and concentration which beside the rheological properties, influence on the quality of final product. With this aim 10 tomato paste samples at various concentrations (17-25%) and breaking temperatures (65-85 $^{\circ}C$) have been produced. The experimental results showed tomato paste behaves as a non-Newtonian semi-fluid which follows power law model that consistency coefficient (K) is supposed function of breaking temperature, concentration and sample temperature with consideration to superimpose function.

***Keywords*—**Breaking temperature, Concentration, Power law, Rheology, Time independent.

I. Introduction

A large part of the world tomato crop is processed into tomato paste, which is subsequently used as an ingredient in many food products, mainly soups, sauces and ketchup. Tomato paste is a dispersion of solid particles (pulp) in an aqueous medium (serum) [3], [4] resulting from the concentration of tomato juice, after the removal of skin and seeds, and contains 24% or more natural soluble solids [2]. Viscosity is one of the main attributes that should be considered to determine the overall quality and consumer acceptability of many tomato products. Furthermore, their flow properties are decisive to assess control and optimization of the unit operations related to the manufacture of different tomato products, i.e. mixing, pumping, filling, etc. different empirical models have been used [5], [6] to characterize the flow behavior of tomato concentrate (i.e. Ostwald de waele; Herschel-Bulkly; Casson, etc). This paper deals with the influence of processing variables (i.e. Breaking temperature, Concentration, Sample temperature) on rheological behavior in order to determine shear stress and apparent viscosity to design various units of tomato paste processing line.

II. Material and Methods

A. Processing of Tomato Paste

Tomato fruits of uniform size, shape and color were washed in water tanks to remove spray residues, micro-organisms, etc adhering to the fruits. Afterwards, the washed tomatoes were chopped into small pieces, pumped into a heat exchanger and preheated to different temperatures. Once this step was completed, the heated tomato pulp was passed through two juice extractor to remove skins and seeds. Finally, the tomato juice was concentrated to different concentrations.

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Nomenclature

$\dot{\gamma}$	shear rate, 1/s
σ	shear stress, Pa
σ_a	average shear stress, Pa
$k_{\dot{\gamma}}$	shear rate conversion factor, dimensionless
k_{σ}	shear stress conversion factor, Pa
B.T.	breaking temperature, centigrade
C	concentration, (%)
D	constant, dimensionless
K	consistency coefficient, $Pa\ s^n$
M	percent torque, dimensionless
N	revolution per minute, RPM
n	flow behavior index, dimensionless
$\bar{n}$	average flow behavior index, dimensionless
T	sample temperature, centigrade
t	time, s

B. Rheological Measurements

Apparent viscosity measurements were carried out with a rotational viscometer (Brookfield DVII+ Pro) and using disk spindle RV6 in a RPM range between 12 and 30. At least two replicates of each test were performed. Unfortunately, the shear rate over a flat disk spindle is non-uniform and difficult to describe mathematically. So the method presented at C. section, which developed by Mitschka (1982) and extended by Briggs and Steffe (1997), was used to convert the RPM and apparent viscosity to shear rate and shear stress.

C. Shear Rate and Shear Stress Calculations

First step is to determine the flow behavior index (n) which can be found from the following equation:

$$M = (\text{constant})\, N^n \qquad (1)$$

Or in the logarithmic form, as

$$Ln\,M = Ln\,K + nLn\,N \qquad (2)$$

The average shear stress is calculated as

$$\sigma_a = k_\sigma(D)(\,percent\ torque\,) \qquad (3)$$

Where the k_σ, changes with the spindle number (Table I). The value of D depends on the total torque capacity of the instrument (Table II).

TABLE I
SHEAR STRESS CONVERSION FACTOR (k_σ) FOR BROOKFIELD SPINDLES

$K_\sigma(Pa)$	SPINDLE NO.
0.035	1
0.0119	2
0.279	3
0.539	4
1.05	5
2.35	6
8.40	7

TABLE II
VALUES OF D FOR TYPICAL BROOKFIELD VISCOMETERS

D	Viscometer model
0.5	(1/2) RV
1	RV
2	HAT
8	HBT

Average shear rate is

$$\dot{\gamma}_a = k_{\dot{\gamma}}\left(N\right) \qquad (4)$$

Where $k_{\dot{\gamma}}$, depends on the numerical value of the flow behavior index (n)

$$k_{\dot{\gamma}} = 0.263\left(\frac{1}{n}\right)^{0.771} \qquad (5)$$

D. Effect of Sample Temperature, Concentration and Breaking Temperature

In this paper some tests have been done to determine the influence of mentioned parameters on rheological behavior. Each of tests have been done at five different shear rates. At first to determine the influence of sample temperature five different temperature at 10, 13, 17, 19, 21 centigrade selected and in order to determine the influence of breaking temperature five different breaking temperature at 65, 70, 75, 80, 85 centigrade selected. Finally in order to determine the influence of concentration, four different concentration at 17, 19, 21, 25% selected.

III. RESULTS AND DISCUSSION

Regarding to previous study [1] and the experiments have been done, the power law equation is suitable to describe the time independent behavior which the K parameter of this model inclusive of breaking temperature, concentration, sample temperature effects. So the K parameter follows as below:

$$K = K_T.K_C.K_{B.T.} \qquad (6)$$

A. Effect of Sample Temperature

Fig. 1 shows the influence of sample temperature on shear stress versus shear rate at constant breaking temperature and concentration. Applying the method on II.C. section to convert the RPM to shear rate and plotting the shear stress versus shear rate values, an excellent fit was obtained with linear regression analysis using the power law model:

$$\sigma = K_T\left(\dot{\gamma}\right)^{n_T} \qquad (7)$$

Or

$$Ln\,\sigma = Ln\,K_T + n_T Ln\left(\dot{\gamma}\right) \qquad (8)$$

$$n_T = 0.233$$

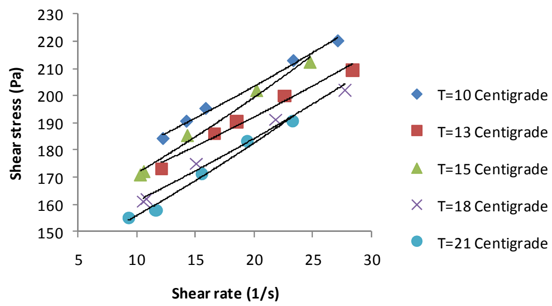

Fig. 1 Shear stress versus shear rate at various temperature and constant concentration and breaking temperature

And plotting K_T versus temperature (Fig. 2) yields:

$$K_T = 120\exp(-0.015T) \qquad (9)$$

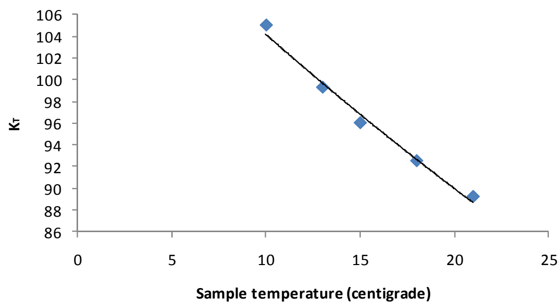

Fig. 2 K_T versus temperature curve

B. *Effect of Concentration*

Fig. 3 shows the influence of concentration on shear stress versus shear rate at constant breaking temperature and sample temperature. Applying the method on II.C. section to convert the RPM to shear rate and plotting the shear stress versus shear rate values, an excellent fit was obtained with linear regression analysis using the power law model:

$$\sigma = K_C\left(\dot{\gamma}\right)^{n_C} \qquad (10)$$

Or

$$Ln\,\sigma = Ln\,K_C + n_C Ln\left(\dot{\gamma}\right) \qquad (11)$$

$$n_C = 0.231$$

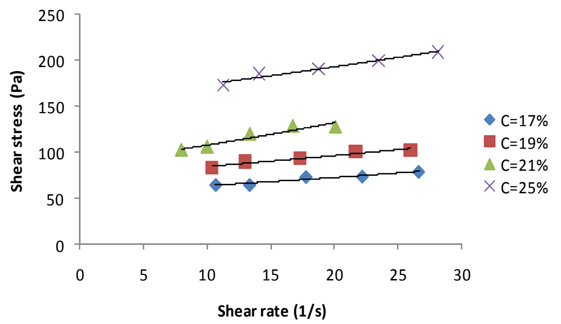

Fig. 3 Shear stress versus shear rate at various concentrations and constant breaking temperature and sample temperature

And plotting K_C versus concentration (Fig. 4) yields:

$$K_C = 3.691\exp(0.1345C) \qquad (12)$$

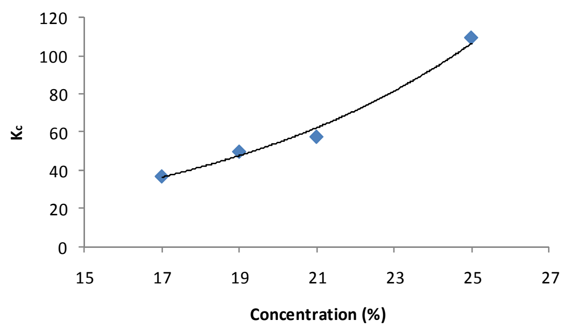

Fig. 4 K_C versus concentration curve

C. *Effect of Breaking Temperature*

Fig. 5 shows the influence of breaking temperature on shear stress versus shear rate at constant both concentration and sample temperature. Applying the method on part II.A. to convert RPM to shear rate and plotting the shear stress versus shear rate values, an excellent fit was obtained with linear regression analysis using the power law model:

$$\sigma = K_{B.T.}\left(\dot{\gamma}\right)^{n_{B.T.}} \qquad (13)$$

Or

$$Ln\,\sigma = Ln\,K_{B.T.} + n_{B.T.} Ln\left(\dot{\gamma}\right) \qquad (14)$$

$$n_{B.T.} = 0.183$$

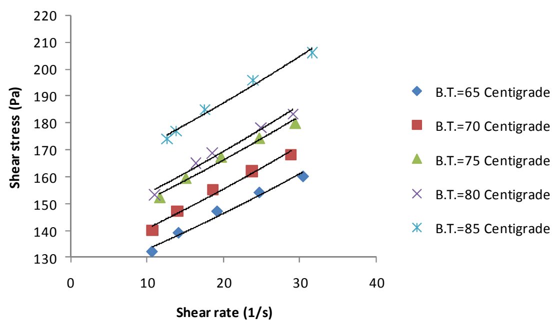

Fig. 5 Shear stress versus shear rate at various breaking temperature and constant sample temperature and concentration

And plotting $K_{B.T.}$ versus breaking temperature (Fig. 6) yields:

$$K_{B.T.} = 39.229\exp(0.0119\,B.T.) \qquad (15)$$

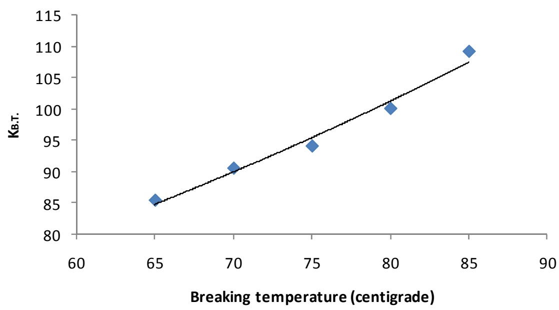

Fig. 6 $K_{B.T.}$ versus Breaking temperature curve

IV. Conclusion

Regarding to the tests have been done, the tomato paste is a non-Newtonian semi fluid which follows the power law mode as below:

$$\sigma = K\left(\dot{\gamma}\right)^{\overline{n}}$$

$$\overline{n} = \frac{n_C + n_{B.T.} + n_T}{3} = 0.215$$

$$K = K_C . K_{B.T.} . K_T$$

$$K_C = 3.691 \exp(0.1345C)$$

$$K_{B.T.} = 39.229 \exp(0.0119T_{B.T.})$$

$$K_T = 120 \exp(-0.015T)$$

By substituting of operation variables such as temperature, concentration, breaking temperature at above mentioned equations, the shear stress could be determined to design different units of tomato paste producing line.

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