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EFFECT OF TEMPERATURE ON THE RHEOLOGICAL PROPERTIES OF PINEAPPLE JUICE (*ANANASCOMOSUS*)

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Abstract-* The rheological property of pineapple juice was investigated over a wide range of temperature (30 to 75°C) using a Couette rotational viscometer. The speed of rotation of the outer cylinder varied from 5.1 to 1021 s^{-1}. The values of viscosity was in the range of 12.65 cP to 300 cP and was dependent on the temperature as well as the shear rate applied. From the results obtain, the test pineapple juice exhibited a non-Newtonian flow behaviour known as shear-thinning behaviour typical of pseudoplastic fluids. This was further confirmed using the Power-law and Herschel-Bulkley model. Arrhenius-type equation was used to analyse the effect of temperature on the juice and equation parameters were obtained. Thus, using the Arrhenius equation and parameters, the viscosity of pineapple juice at any temperature for a specific shear rate can be predicted. Coefficient of determination obtained were between 0.9 – 0.95

Keywords – Viscosity; Pineapple Juice; Temperature, Shear rate, Arrhenius Model

I. INTRODUCTION

Rheology of foods play an important role in the food industry. Concerned with flow and deformation of material that takes place when stress is applied to the food materials, it serves as a tool in the production and processing of food products. Rheological measurements are used for physical characterisation of raw materials, intermediate products during manufacturing and finished products. It is applicable to all materials ranging from gases to liquids to solids and semi-solids, and in areas of food acceptability, processing and food handling [1, 2, 3]

Foods are complex materials in structure and rheology. They usually consists of mixtures of solids as well as liquid structural components [4]. When stress is applied to any food material like liquid food, a strain develops in the materials causing the deformation of materials as in flow of juices through pipes or movement of semi-solid foods in ice cream factory [3]. Rheology attempts to define the relationship between stress acting on a given materials and the resulting shear strain developed in this material. The parameter viscosity is generally used to represent the rheological properties of liquid food. For juice and pulp, it is an important parameter with respect to their process and flow behaviour performance [5], equipment design and consumer acceptance as well as selection of evaporators used for concentrating juices [1].

Fruit juice is the liquid extracted from a fruit, usually a ripe one. It is commonly consumed as a beverage or used as flavouring ingredient in foods. [1]and[3]observed that most fluids especially food materials do not follow the Newtonian model hence their viscosity varies with shear rate. Due to the high concentration of macromolecules such as pectin, starch and cellulose, the rheological behaviour of fruits juices and pulps are commonly non-Newtonian[5, 6]. Their flow behaviours can be described by rheological models like Herschel-Bulkley, Power Law, Newtonian and Bingham models.

Pineapple (*Ananascomosus*) is a tropical plant with edible multiple fruit consisting of coalesced berries. It is said to be the most economically significant plant in the Bromeliaceae family. They are used as raw materials for various purposes in the food industry such as production of juices, jellies, nectars, concentrates. Many studies have been published on the characteristics and physical properties of pineapple juice. Conventionally, they are processed and preserved in liquid or semi-solid states. However, preservation of juices is not economical since the water content in fruit juices is very high (about 75% to 90%) [7]hence, they are usually concentrated. This is not only to provide microbiological stability but also for purpose of economical packaging, transportation and distribution of the final product [5]. During this process, the pineapple juice is subjected to series of temperature changes which affects the taste, colour and texture of the final product [5]. Hence the aim of this paper was to study the effect of temperature variation of the viscosity of fruit juice; with the data, classify the fruit and develop a model that can be used to predict the viscosity of pineapple juice at a particular temperature.

II. MATERIALS AND METHODS

Sample preparation

Ripe pineapple (*Ananascomusus*) fruits were purchased from a local market, washed, peeled and the pulp portion was sliced to separate the stick, all operations were done manually. The slices were blended and then filtered using a fine sieve to get pineapple juice of uniform consistency and particle size. The juice was stored in a 3L container for analysis. All the experimental measurements were conducted

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with samples from the same batch of concentrated juice produced from available seasonal fruits.

Rheological measurements

The Fann© Model 35 Viscometer was used. It is a couette rotational viscometer that has six-speed (3, 6, 100, 200, 300, and 600 rpm) for operation using electrical power. It included a R1 rotor sleeve, B1 bob, F1 torsion spring, and a stainless steel sample cup for testing.

Approximately 350 ml of the sample were added to the stainless steel sample cup. The test fluid (juice) was contained in the annular space between the outer cylinder and the inner cylinder, otherwise called the bob. After that, the speed switch was set to a high or low speed position to select the desired speed, then the motor was turned on and the gear shift knob was moved to the position that corresponded to the desired speed. Viscosity measurement were made when the rotation of the outer cylinder caused a viscous drag to be exerted by the fluid thus creating a torque on the bob. This torque was transmitted to a precision spring where its deflection was measured. The viscosity was indicated on the dial with a standard rotor, bob and torsion spring combination (F1-B1-F1).

The experiments were conducted under constant temperature with varying shear rate, which was changed by changing the rotor speed. The varying shear rate was generated for different temperatures (30, 35, 40, 45, 50, 55, 60, 65, and 70°C) to analyse the flow behaviour of pineapple juice. Temperature was measured using a digital thermometer and was controlled using an electric laboratory water bath. Three replications were made and at each, a fresh sample was prepared. The average mass concentration for the pineapple juice used was 6.92g/50ml with a variation of ±0.006.

Data Analysis

The viscosity measurement were carried out at several speeds (3, 6, 100, 200, 300, 600 rpm). Conversion of viscosities at these test speedswere necessary because of the type of viscometer used. At 300 rpm, the viscosity in centipoise was read directly from the dial which, according to the manual, is the Newtonian viscosity of the fluid. Multipliers of dial readings were made available on the viscometer manual (Manual No. 208878, Revision O)[8].

The viscosity of the pineapple juice was calculated, at each temperature, using equation (1)

$$\mu(cP) = (100)\frac{\tau}{\gamma} \quad \textbf{(1)}$$

$$\tau = k_1 k_2 \theta \quad \textbf{(2)}$$

$$\gamma = k_3 N \quad \textbf{(3)}$$

Whereτisthe shear stress, dynes/cm^2 (eq. 2); γ is the shear rate, sec^{-1} (eq. 3); μ is the viscosity (cP); k_1 is the torsion spring constant, dyne-cm/degree deflection; k_2 is the shear stress constant for the effective bob surface, cm^{-3}; k_3 is the shear rate constant, sec^{-1} per rpm; θ is Fann viscometer reading (dial reading); N is the rate of revolution of the outer cylinder (rpm) and 100 is the conversion factor, (1 poise = 100 cP)

TABLE 1CONSTANT FOR VISCOSITY CALCULATIONS [8]

Constant	Value
Shear rate constant, k_3, (sec^{-1} per rpm)	0.01323
Shear stress constant for effective boob surface k_2,(cm^{-3})	1.7023
Torsion spring constant k_1, dyne-cm/degree deflection	386

Rheological models

Experimental data were fitted into the Ostwald-de Waele (power law) model using Equation4 and Herschel-Bulkley model using Equation 5. The power law model is widely used because it gives a good approximation of the fluid flow behaviour; Herschel-Bulkley is an extension of the power law model to include a yield stress term which can be exhibited in foods. From the power law model, the apparent viscosity for each temperature/shear rate combination can be calculated using Equation (6) when the shear rate, flow behaviour and consistency index are known.

$$\tau = k\dot{\gamma}^n \quad \textbf{(4)}$$

$$\tau = \tau_o + k\dot{\gamma}^n \quad \textbf{(5)}$$

$$\mu_a = k\dot{\gamma}^{n-1} \quad \textbf{(6)}$$

Where, τ is the shear stress, τ_o is the yield stress; γ is shear rate, μ_a is apparent viscosity, k is the consistency index and n is the flow behaviour index.

III. RESULTS AND DISCUSSION

The rheological behaviour of the pineapple juice was analysed at shear rates of 5.11, 10.2, 170, 340, 511, 1021 s^{-1} for temperatures 30, 35, 40, 45, 50, 55, 60, 65, and 70°C respectively. Shear rate and shear stress were computed using the experimental results obtained. The variation of shear stress and shear rate are displayed in Fig. 1. It can be seen from the plot that shear rate and shear stress had a non-linear relationship typical of non-Newtonian fluids. Data from the experiment where further fitted into commonly used non-Newtonian models to obtain the rheological parameters of the test pineapple juice.

Viscosity changed with shear stress and as such was called the apparent viscosity of pineapple juice. A plot of apparent viscosity versus shear rate (Fig. 2) showed that for a given temperature, the pineapple juice could not be defined by a single viscosity rather viscosity decreased as shear rate increased. The behaviour is known as shear-thinning flow behaviour and the fluids which display them are called pseudoplastic fluids [3, 9]

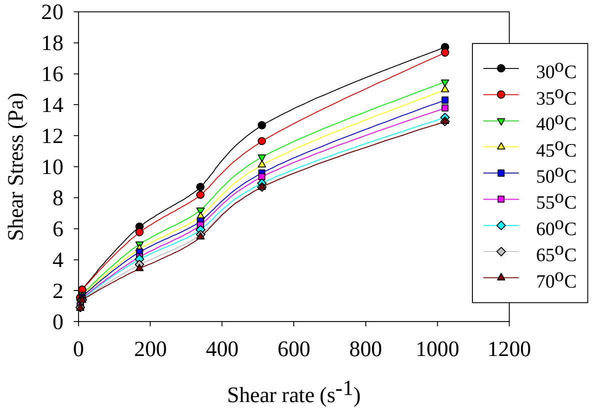


Fig.1 Rheogram(shear stress versus shear rate relationship) of pineapple juice (6.9g/50ml) at 30, 35, 40, 45, 50, 55, 60, 65, 70°C

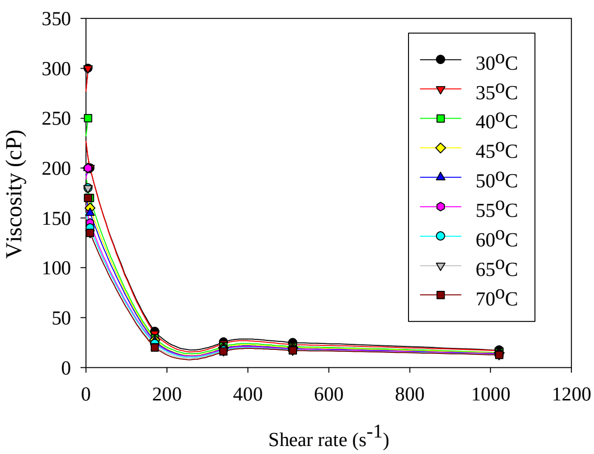


Fig.2 Relationship between shear rate and viscosity at varying temperature.

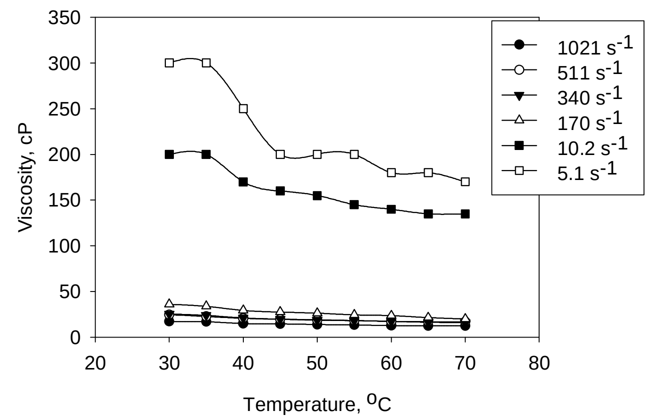
Molecules of the pineapple juice temporarily changed orientation becoming more parallel to the rotating bob so that the hindrance to its motion decreased. The faster the speed, the lower the viscosity because the molecule structure had less chance to slide together. Apparent viscosity of pineapple juice, initially, decreased significantly with increasing shear rate. At high shear rate, it reached some asymptotic value, that is, the decrease in viscosity was no longer as significant as it was at lower shear rate rather, the curve flattened out into a near straight line due. This, according to Rao, is the three stage viscous response when a shear-thinning fluid is sheared over a wide range of shear rate. The first stage he said is the viscosity of such shear thinning fluid at low shear rate behaving like Newtonian fluid then transitioning to pseudoplastic at second stage. At the last stage, at high shear rate, the relationship between the viscosity and shear stress was limiting and constant infinite shear viscous. In [1], they observed that if experiment was conducted at a much wider range of shear rate, the apparent viscosity would have decreased to a constant value where it would not be affected by change in shear rate.The experimental results indicated a similar trend with this theory. Data obtained from this experiment, fitted into the second and third stage described above as shown in Fig.2.

Effect of temperature

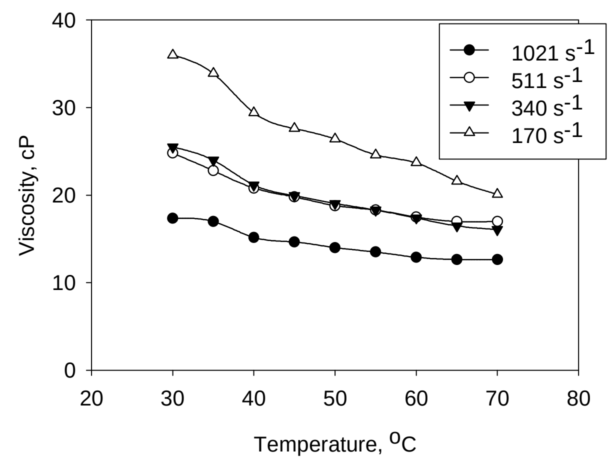
Temperature, according to literature, is known to have an inversely proportional relationship with the viscosity of liquids as is seen also in[1] [3] [5].This effect reduces the resistance to flow thus increasing the flowability of the liquid food. Experimental results revealed that temperature affected the viscosity of pineapple puree. For the shear rate range considered, the viscosity of the juice decreased as temperature increased (Fig.3). The Arrhenius equation (Equation 6) was used to further represent the effect of temperature on viscosity of pineapple juice.

$$\mu = \mu_o e^{E/RT} \qquad (7)$$

where, $\mu_o$is Arrhenius factor, *E* is activation energy in J/g mole, *T* is temperature in Kelvin, and R is universal gas constant = 8.23 J/g mole K.



(a)



(b)

Fig.3Effect of temperature on viscosity of pineapple juice at different viscometer speed (a) overall speed range (b) expanded view for 1021,511, 340 and 170s^{-1}

The effect of temperature on the apparent viscosity of the pineapple juice was evaluated according to this method and data were plotted in Fig.4. As expected, a clear linear dependence was observed, that is viscosity decreased with increasing temperature.

The values of the parameters obtained from Arrhenius model were obtained by linear regression analysis and are tabulated in Table 2. These values of activation energy for the pineapple juice were significantly higher when the temperature was low than when higher. It increased from about 7.33 kJ/g mol to more than 12 kJ/g mol.

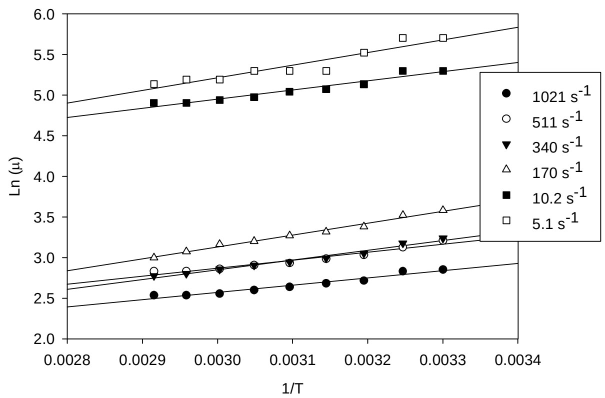


Fig. 4 Application of Arrhenius equation for effect of temperature on viscosity of pineapple juice

TABLE 2 PARAMETERS OF ARRHENIUS MODEL (CONSTANT AND ACTIVATION ENERGY) FOR PINEAPPLE JUICE AT CONCENTRATION 6.9g/50ml

Shear rate(s^{-1})	Arrhenius constant	Activation energy (kJ/g mol)	R^2
1021	0.9	7.33	0.95
511	0.92	8.1	0.95
340	0.47	9.9	0.98
170	0.28	12.08	0.99
10.2	4.76	9.3	0.94
5.1	1.71	12.83	0.89

Rheological models

Data were fitted into the power model and Herschel-Bulkley model to obtain the best model that describe the pineapple juice flow.

Power law model is a two-parameter model that is widely used to characterise flow behaviour of liquid food. This is mainly because the rheological behaviour of food is represented by a straight line [1]. Values of the shear stress and shear rate were fitted into Equation (4) using the SigmaPlot 12.5 software to obtain the power law parameters (Table 3).

The results showed a good fitting to power law with r-squared values of approximately 0.99. The flow behaviour index of the samples found to be between 0.56 and 0.69 across the temperature range considered. This further confirmed the shear thinning flow behaviour (or pseudoplastic nature) that was exhibited by the pineapple juice sample. The results agree with those obtained in [1, 5, 6, 10]

From the Herschel-Bulkley analysis, yield stress in the range of $0.79<\tau_o$ (Pa) <1.28 was obtained. This range was equivalent to the low rotational speed applied by the viscometer at which no significant change was observed though as temperature increased, the values became lower for the same speed (Table 4). Comparing data predicted using these two models with the experimental data, a good r-square value was obtained from both models. The standard deviation for the Herschel-Bulkley model was higher than the power model as a result of the model over predicted most of the data. The most important parameter was the flow behaviour index which was below 1 (n<1) for both models.

TABLE 3 PARAMETERS FOR POWER-LAW MODEL DERIVED BY REGRESSION ANALYSIS

Temp (°C)	Ostwald-de Waele model		
	n	K (Pa s^n)	R^2
30	0.561	0.363	0.989
35	0.590	0.288	0.988
40	0.600	0.241	0.988
45	0.624	0.198	0.989
50	0.623	0.190	0.988
55	0.631	0.173	0.988
60	0.632	0.165	0.988
65	0.662	0.132	0.985
70	0.688	0.110	0.983

TABLE 4 PARAMETERS HERSCHEL-BULKLEY MODEL DERIVED BY REGRESSION ANALYSIS

Temp (°C)	Herschel-Bulkley model			
	τ_o	K (Pa s^n)	n	R^2
30	1.05	0.183	0.653	0.994
35	1.28	0.113	0.717	0.997
40	1.02	0.106	0.711	0.995
45	0.878	0.094	0.724	0.995
50	0.891	0.086	0.731	0.995
55	0.850	0.079	0.738	0.994
60	0.787	0.077	0.734	0.994
65	0.810	0.058	0.773	0.993
70	0.793	0.049	0.799	0.99

IV. CONCLUSIONS

From the study, we observed that pineapple juice exhibited a shear-thinning flow behaviour which is common characteristics of pseudoplastic fluids. The viscosity of the juice decreased as temperature increased. Arrhenius equation was used to further analyse this effect and parameters where obtained which can be used to predict the viscosity of pineapple juice at any temperature for the specific shear rate. It must be noted, since the apparent viscosity of pineapple juice is dependent on the shear rate applied, the value of shear rate must be specified whenever the apparent viscosity is given hence, this will be meaningless.

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