# INFLUENCE OF TEMPERATURE AND SOLUBLE SOLID CONTENTS ON RHEOLOGICAL PROPERTIES OF THE JOSAPINE VARIETY OF PINEAPPLE FRUIT (*ANANAS COMOSUS* L.).

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## *ABSTRACT*

*The rheological behaviour of Josapine pineapple juice has been determined over a wide range of temperature (5 to 65°C) and soluble solid contents (4.3 to 14.1°Brix), using a rotational rheometer as a measuring system. The speed of the rotating cylinder varied from 10 to 317* $s^{-1}$*. Based on the obtained result it was shown, that Josapine pineapple juice has a Newtonian behaviour. The values of viscosity were in the range from 25.2 to 49.2 mPas and strongly depend on temperature and soluble solids content. The effect of temperature on that juice can be described by an Arrhenius-type equation. It was found that the activation energy was in the range 651.5 to 1259.68 Calmol*$^{-1}$*, depending on the concentration. To study effect of concentration on the viscosity, the power-law and exponential equations were used. Finally, an equation describing the combined effect of temperature and concentration on viscosity is given.*

***Keywords:*** *pineapple; josapine; sugar; acidity; water activity; viscosity*

## INTRODUCTION

In Malaysia, pineapple is known as nanas locally. There are two pineapple commercial varieties in the country. For canning, they are known as "nanas merah" (red pineapple) or "nanas hijau" (green pineapple). For eating raw, the nanas Sarawak (Sarawak pineapple), nanas Josapine (Josapine pineapple) and nanas Moris (Moris pineapple) is used. Josapine is a hybrid between 'Johor' (‘Singapore Spanish’ x ‘Smooth Cayenne’) and 'Sarawak' (‘Smooth Cayenne’) released by the Malaysian Agriculture Research and Development Institute (MARDI, 2005) for the fresh fruit. The pineapple industry of Malaysia is the oldest agro-based export-oriented industry from 1988. Nearly 90% of the pineapple crop in Malaysia is planted on peat soil.

Changes in the physical and chemical properties of food components cause of the temperature changes. Which influence the overall properties of the final product such as taste, appearance, colour and texture. A lot of foods are subjected to variations in the temperature during production, transport, storage, preparation and consumption such as cooking, freezing, chilling, evaporation etc (Canela, Alvarez & Maceiras, 2005).

Due to the high concentration of macromolecules such as pectin, starch and cellulose, fruit juices and pulps are commonly non-Newtonian fluids, which contribute to rheological behaviour (Virginia et. al., 2000). Viscosity of juice and pulp are an important parameter with respect to their process and flow behaviour performance. According to Saravacos (1970), the rheological behaviour of liquid and semi-solid foods is important for the design of processing equipment, coating, process control, quality control and product development. A number of studies have been reported in rheological behaviour such as products including products from mango (Bhattacharya & Rastogi, 1998), cherry (Virginia et. al., 2000), strawberry (Lesław Juszczak & Teresa Fortuna, 2003), caja juice (Assis, Tadini & Lannes, 2005), peach (Ibarz, Gonzalez, Esplugas & Vicente,1992), orange (Ibarz, Gonzalez & Esplugas (1994) etc.

$$\tau = \eta \dot{\gamma} \tag{1}$$

$$\tau = K\left(\dot{\gamma}\right)^{n} \tag{2}$$

The aims of this study was to measure rheological properties of Josapine pineapple juice as a function of temperature and soluble solid contents; to fit experimental data to rheological model existing in literature

## EXPERIMENTAL

### Preparation of samples

Pineapple (*Ananas Comosus* L.) from Josapine variety was obtained from a plantation in Johor, a southern state in Malaysia, during the 2005 season. Pineapples were harvested at stage of maturity 1 (Immature fruit. All eyes are glossy bluish dark green with reddish bractea). At this maturity stage, the flesh of fruit is very firm and sour. The stage of maturity follows the standard specification and grade by FAMA (Federal Agricultural Marketing Authority). After harvesting, the pineapple fruits were stored at room temperature of 25°C, RH of 52% until they reached the desired ripeness stage required for the experiment. The fruits were selected based on the percent skin yellowing. Pineapple fruits at stage of maturity 7 (full orangy yellow, fully ripe fruit and 11 days in storage) were selected for this experiment. The pineapple juice was prepared by peeling and blended with a Power Juicer (Smart Shop TM).

The concentration of soluble solids of Josapine juice was 14 °Brix, determined by refractometry using ABBE-1T (Atago) refractometer at a temperature 25°C. Samples with lower soluble solids contents were obtained by dilution the original concentrated juice with distilled water.

### Chemical analyses

#### *Soluble solids contents*

A refractometer (Atago, ABBE-1T) was used at the working temperature 25 °C. The measured concentration of soluble solids in the original concentrated Josapine pineapple juice was 14.1 °Brix. The soluble solids of the other samples, with lower contents, were measured after diluting with distilled water.

#### *pH*

A Mettler Toledo (model S47-K) pH-meter was used at the working temperature 25 °C. The pH of the original concentrated Josapine pineapple juice was 3.81.

#### *Sugar content*

Glucose, fructose and sucrose were determined by HPLC (Waters, US). Total sugar was determined by summation of individual values of glucose, fructose and sucrose. The glucose, fructose and sucrose content were 1.8%, 2.8% and 8.1% respectively. The total sugar of Josapine pineapple juice was 12.7%.

#### *Acidity*

The acidity of Josapine pineapple juice was determined by titration (Metrohm model ) with NaOH 0.1 N. The result of acidity of the original concentrated Josapine pineapple juice was 0.13 mol/liter. All the experiment was three times replicate.

#### *Total insoluble solids*

Oven method was used in order to determine the total insoluble solids content of Josapine pineapple juice. About 10g of sample was placed in a stainless steel dish and put into oven at 105°C for about 24 hours. After 24 hours, the sample was taken out and cooled down before the sample is weighed. The percentage of total insoluble solid can calculate by the following equation;

$$\%\ \text{Total insoluble solid} = \frac{x}{y} \times 100\%$$

Where, x is weight of sample after drying and y is weight of sample before drying, expressed in unit gram. All the experiment was three times replicate.

***Water activity***

Water activity was determined by Water Activity Meter (Aqualab Series 3TE) at the working temperature 25 $^{o}$C. All the experiment was three times replicate.

**Rheological measurements**

The rheological properties of Josapine pineapple juice were carried out using a rotational Physica MCR 500 rheometer (Physica Messtechnic GmbH, Stuttgart, Germany) using a concentric cylinder geometry (FL100/Q1). The temperature was regulated by a Paar Physica circulating bath and a controlled peltier system (TEZ 150P-C) with an accuracy of ± 0.1 $^{o}$C. The data of the rheological measurements were analyzed with the supporting rheometer software US 200 V2.3. The speed of the rotating cylinder varied from 10 to 317 $s^{-1}$ and temperatures was constant at 5, 15, 25, 35, 45, 55 and 65 $^{o}$C. The instrument can be operated at 10 different speeds; shear rate and shear stress were obtained.

The rheological behaviour of the Josapine pineapple juices at different total soluble solids (14, 10.1, 8.3, 6.1 and 4.3 $^{o}$Brix) and temperatures (5, 15, 25, 35, 45, 55 and 65 $^{o}$C) were studied. All the experiments were replicated.

**Data analysis**

Fitted models were obtained by using nonlinear estimation procedure from the statistical program SPSS v. 11.5. The suitability of the fitted models was evaluated by the determination coefficient ($r^2$), the significance level ($p<0.01$), and residual analysis.

## RESULT AND DISCUSSION

The water activity of Josapine pineapple juice at different concentrations are given in Table 1. As was to be expected, the water activity ($a_w$) decrease with increases in concentration of juice. According to Chen (1987), water activity ($a_w$) is the most widely used parameter to indicate the availability of water in food systems for predicting food stability

*Table 1: Water activity of Josapine pineapple juice at different concentration*

| C ($^{o}$Brix) | Water activity |
|---|---|
| 14.0 | 0.975 ± 0.00 |
| 10.1 | 0.976 ± 0.00 |
| 8.3 | 0.982 ± 0.00 |
| 6.1 | 0.983 ± 0.00 |
| 4.3 | 0.984 ± 0.00 |

The rheograms were obtained for dilution of Josapine variety of pineapple juice at 14.0, 10.1, 8.3, 6.1 and 4.3$^{o}$Brix, in replicate, and at temperatures from 5, 15, 25, 35, 45, 55 and 65 $^{o}$C. The typical rheograms of Josapine pineapple juices at temperatures 15, 25, 35, 45, 55 and 65 $^{o}$C and at concentration 14.0 $^{o}$Brix are shown in Figure 1.

The experimental results of the variation of shear rate ($\dot{\gamma}$) and shear stress ($\tau$) indicate the Newtonian behaviour. The experimental data of the juices has been fitted to Newton's law (equation 1) by the statistical program SPSS method was satisfactory and given us to calculated the viscosity coefficients. Similar curves were observed for samples with different soluble solids content. It can be seen that values of shear stress decreases with temperature decreases. For sample with higher soluble solids content, the effect is more visible.

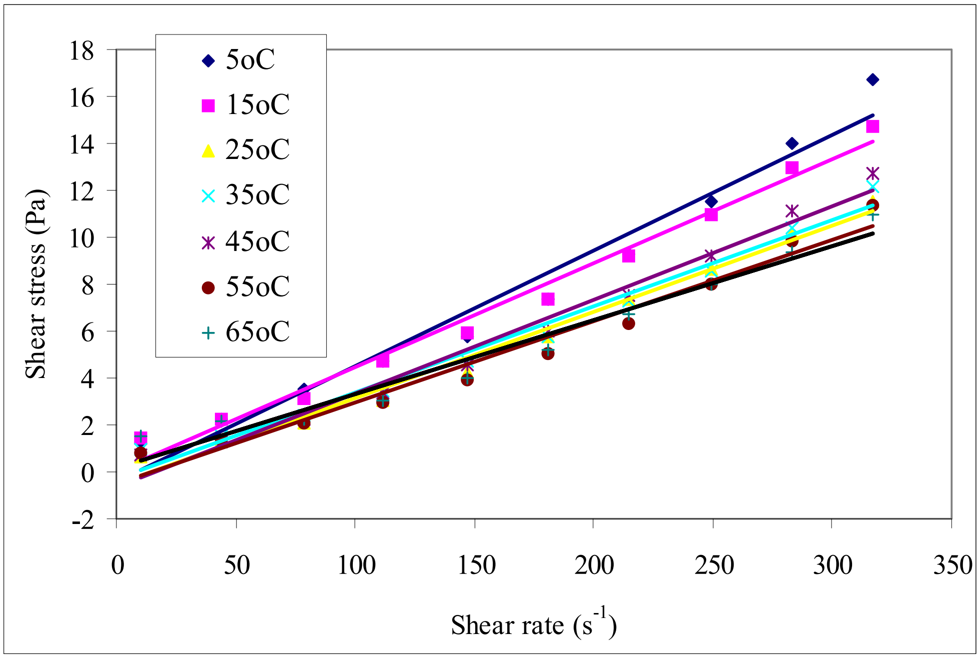


*Figure 1: Rheograms showing the effect of the temperature on juice at 14.0 °Brix.*

Figure 2 shown the rheograms at concentration 14.0, 10.1, 8.3, 6.1 and 4.3°Brix and at temperature 65 °C. Similar curves were obtained for samples at other temperature. The result shown that the values of shear stress decreases with decreases in soluble solid content. The flow curves shown on Figure 1 and 2 indicated the Newtonian behaviour of Josapine pineapple juice at shear rate 10 to 317 $s^{-1}$. This same behaviour has also been reported for strawberry juice by Lesław Juszczak & Teresa Fortuna (2003), clarified peach juices by Ibarz, Gonzalez, Esplugas & Vicente (1992), caja juice by Assis, Tadini & Lannes (2005), clarified orange juices by Ibarz, Gonzalez & Esplugas (1994) and sloe juices by Ibarz, Garvin & Costa (1996).

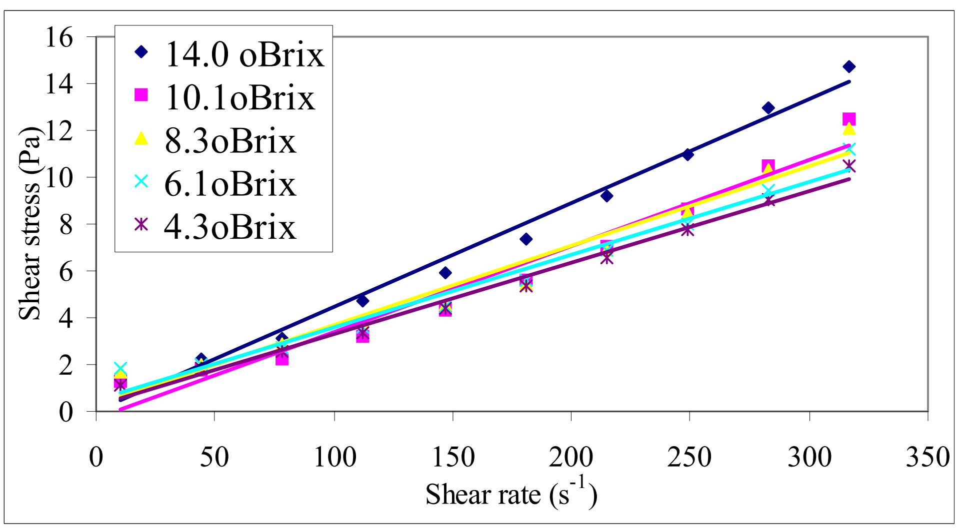


*Figure 2: Typical rheograms obtained for dilution of Josapine variety of pineapple juice at 14.0, 10.1, 8.3, 6.1 and 4.3°Brix, all obtained at 65 °C.*

The values of viscosity were obtained by fitting the experimental flow ($\tau, \dot{\gamma}$) curves to equation (1) are given in Table 2. The fits and estimates of the viscosity are significant at coefficients level ($R^2$) higher than 0.96. The values of viscosity were in the range 25.2 to 49.2 mPas. These values are strongly depending on soluble solids content and temperature. It can be seen that values of viscosity decreased with increased in temperature, especially more visible for samples with higher soluble solids content.

**Effect of temperature**

The variation in viscosity with temperature on the flow behaviour of fluid foods can be described by the Arrhenius relationship-type exponential equation (Ibarz et. al., 1994; Vitali & Rao, 1982 and Lesław Juszczak & Teresa Fortuna, 2003.

$$\eta = K_o \exp\left(\frac{E_a}{RT}\right) \tag{3}$$

where $K_o$ is a constant, $E_a$ is the activation energy of flow, R is the gas constant and T is the temperature in K.

Table 2: Relationship between viscosity and soluble solid contents of Josapine pineapple juice at different temperatures

| T ($^o$C) | C ($^o$Brix) | $\eta$ (Pa s) | $R^2$ |
|---|---|---|---|
| 5 | 14.0 | 0.0492 | 0.9689 |
| | 10.1 | 0.039 | 0.9813 |
| | 8.3 | 0.0356 | 0.9808 |
| | 6.1 | 0.0332 | 0.9753 |
| | 4.3 | 0.0318 | 0.9840 |
| 15 | 14.0 | 0.0442 | 0.9859 |
| | 10.1 | 0.0366 | 0.9608 |
| | 8.3 | 0.0338 | 0.9611 |
| | 6.1 | 0.0310 | 0.9717 |
| | 4.3 | 0.0290 | 0.9868 |
| 25 | 14.0 | 0.0367 | 0.9858 |
| | 10.1 | 0.0364 | 0.9791 |
| | 8.3 | 0.0330 | 0.9904 |
| | 6.1 | 0.0293 | 0.9780 |
| | 4.3 | 0.0287 | 0.9888 |
| 35 | 14.0 | 0.0367 | 0.9808 |
| | 10.1 | 0.0315 | 0.9791 |
| | 8.3 | 0.0311 | 0.9853 |
| | 6.1 | 0.0298 | 0.9840 |
| | 4.3 | 0.0280 | 0.9823 |
| 45 | 14.0 | 0.0355 | 0.9828 |
| | 10.1 | 0.0314 | 0.9768 |
| | 8.3 | 0.0313 | 0.9764 |
| | 6.1 | 0.0303 | 0.9740 |
| | 4.3 | 0.0273 | 0.9787 |
| 55 | 14.0 | 0.0347 | 0.9682 |
| | 10.1 | 0.0310 | 0.9707 |
| | 8.3 | 0.0303 | 0.9731 |
| | 6.1 | 0.0265 | 0.9819 |
| | 4.3 | 0.0259 | 0.9780 |
| 65 | 14.0 | 0.0314 | 0.9600 |
| | 10.1 | 0.0281 | 0.9668 |
| | 8.3 | 0.0264 | 0.9794 |
| | 6.1 | 0.0262 | 0.9781 |
| | 4.3 | 0.0252 | 0.9818 |

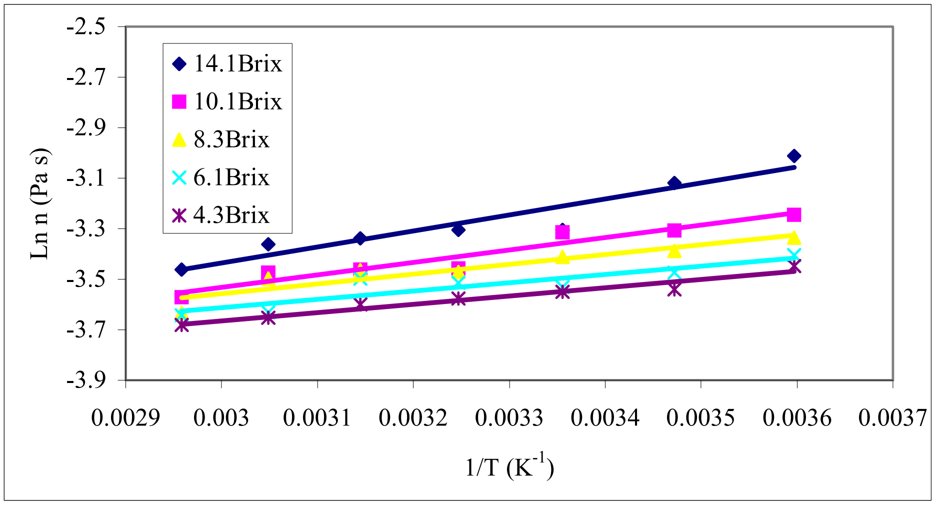


*Figure 3: Effect of temperature on viscosity of Josapine pineapple juice at different soluble solids contents*

According to Arrhenius relationship, the effect of temperature on the viscosity of the pineapple juice was plotted in Figure 3. The values of the parameters from this equation are shown in Table 3. The activation energy increases and the values of material constant decrease with the soluble solids contents. This tendency is similar to other juices such as strawberry juice by Lesław Juszczak & Teresa Fortuna (2003), clarified peach juices by Ibarz, Gonzalez, Esplugas & Vicente (1992), clarified orange juices by Ibarz, Gonzalez & Esplugas (1994) and sloe juices by Ibarz, Garvin & Costa (1996). According to Lesław Juszczak & Teresa Fortuna (2003), the values of flow activation energy in Newtonian fluids are significantly higher than the corresponding values for non-Newtonian fluids of the same solids concentration. The value of flow activation energy in the Newtonian fluids foods increases from about 14.4 kJ/mol (water) to more than 60 kJ/mol (concentrated juices and sugar solution).

*Table 3: Arrhenius-type parameters relating the effect of temperature on Josapine pineapple juices*

| Concentration (°Brix) | $K_o$ (Pa s) | $E_a$ (Cal/mol) | $R^2$ |
|---|---|---|---|
| 14.0 | $4.80 \times 10^{-3}$ | 1259.68 | 0.9013 |
| 10.3 | $6.70 \times 10^{-3}$ | 976.29 | 0.9295 |
| 8.3 | $8.90 \times 10^{-3}$ | 771.49 | 0.8682 |
| 6.1 | $9.98 \times 10^{-3}$ | 658.03 | 0.8128 |
| 4.3 | $9.58 \times 10^{-3}$ | 651.50 | 0.9516 |

**Effect of the concentration**

Variation of viscosity with the soluble solids content can be described by two different models; the power type or exponential type (Ibarz et. al., 1992, 1994, 1995; Giner at.al., 1996; Hernandez, et.al., 1995; Hassan & Hobani, 1998; Lesław Juszczak & Teresa Fortuna, 2003).

$$\eta = \eta_1.(C)^{b_1} \tag{4}$$

$$\eta = \eta_2.\exp(b_2.C) \tag{5}$$

In equation (4) and (5), C the concentration in °Brix and $\eta_i$ and $b_i$ are constants.

For different samples with different temperatures at different soluble solids contents, the values of parameter of these equations were fitted using the SPSS method. In both cases the fit and estimates of parameters were significant at a probability level of 90%. Table 4 shows the estimates of the parameters obtained by the exponential equation, gives better fit than the power-law model.

*Table 4: Influence of the soluble solids content on viscosity of Josapine pineapple juices at different temperatures (using exponential equation)*

| Temperature, T ($^oC$) | $\eta_2$ (Pa s) | $b_2$ | $R^2$ |
|---|---|---|---|
| 5 | 0.0253 | 0.0545 | 0.9673 |
| 15 | 0.0255 | 0.0373 | 0.9673 |
| 25 | 0.0255 | 0.0287 | 0.9612 |
| 35 | 0.0250 | 0.0262 | 0.9586 |
| 45 | 0.0253 | 0.0240 | 0.9214 |
| 55 | 0.0245 | 0.0235 | 0.9620 |
| 65 | 0.0226 | 0.0223 | 0.9487 |

## The combined effect of temperature and concentration

For practical applications, it is important to obtain a single expression that combined effect of temperature and soluble solids contents on Josapine juice viscosity. To get an equation which relates the parameters that are presented in the equation of Arrhenius to the juice concentration. According to Table 2, the activation energy of flow ($E_a$) increases and the constant ($K_o$) decreases with increases in soluble solids content of juice.

To obtain values of $E_a$ and $K_o$ were fitted to different equations including the concentration of juice, it seems that the exponential model gives better fit than the power-law model. The equation of $E_a$ was:

$$E_a = 444.5 \exp (0.0734C) \quad (6)$$

With a correlation coefficient, $R^2 = 0.9622$, in which $E_a$ is the activation energy of flow in Cal $mol^{-1}$ and C is the concentration of juice in $^o$Brix. The best line of the logarithm of the activation energy of flow versus the concentration of juice in $^o$Brix are shown in Figure 4.

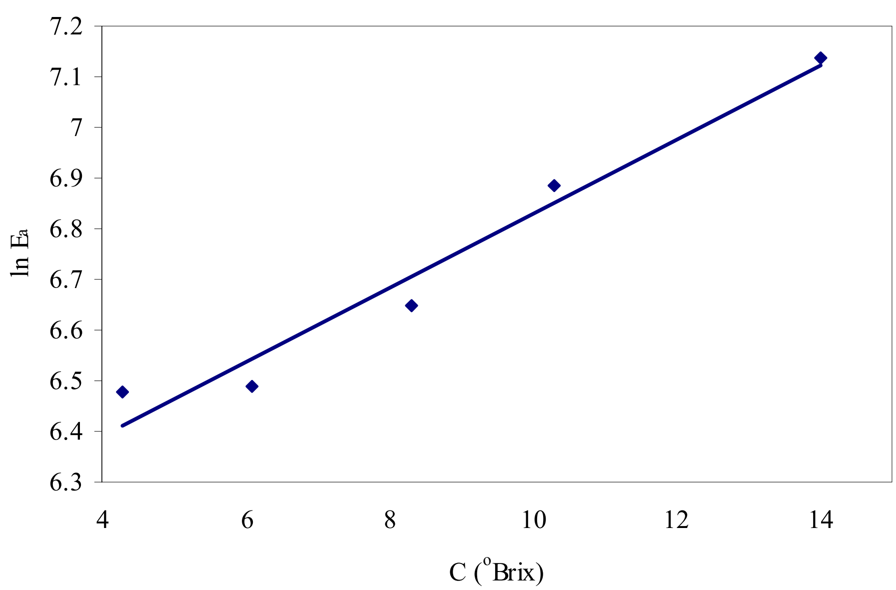


*Figure 4: Change in the activation energy of flow ($E_a$) with the concentration of Josapine pineapple juice in $^o$Brix*

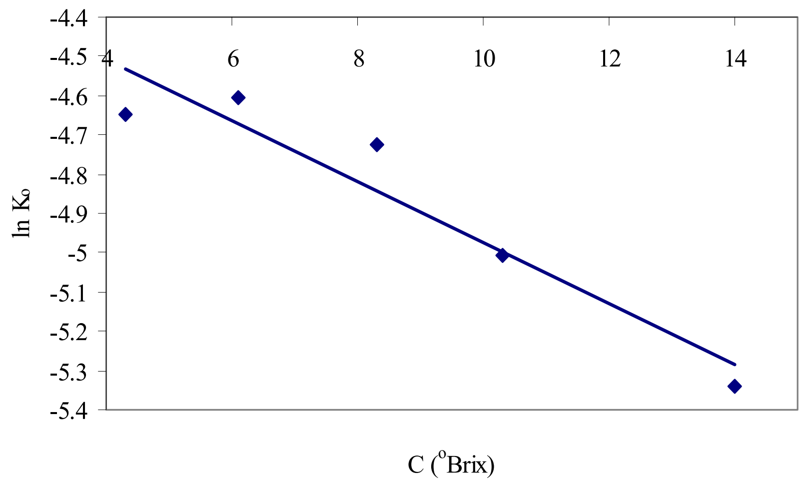


*Figure 5: Change in the Arrhenius constant $K_o$ with the concentration of Josapine pineapple juice in $^o$Brix*

The logarithm of the Arrhenius constant ($K_o$) versus the concentration of Josapine pineapple juice in $^o$Brix and the best fit line are shown in Figure 5. The equation for Ko was:

$$K_o = 0.015 \exp(-0.0777\, C) \tag{7}$$

With a correlation coefficient, $R^2 = 0.9076$, in which $K_o$ is the Arrhenius constant and C is the concentration of juice were expressed in Pa s and in $^o$Brix respectively. The fit and the estimates of the parameters in both equation (6) and (7) were significant at a probability level of 90%.

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