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## Kinetic Studies on Cooking of Pineapple Bakery Jam

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### ABSTRACT

Cooking rate of pineapple bakery jam was investigated and the effect of cooking temperature, stirring speed and batch volume on rate constant was examined. The linear relationship between the logarithmic total soluble solids gain ratios of cooked jam and the cooking time showed that the cooking rate followed the equation of first-order chemical reaction. In this present study, the cooking rates were increased with cooking temperature and stirring speed, but it decreased with increasing batch volume. The activation energy of cooking process was 42.49 kJ mol<sup>-1</sup>. The recommended cooking temperature for cooking of pineapple bakery jam was 90°C as the jam was burnt on the surface of the cooker and undesirable caramel flavour was resulted at cooking temperature of 100°C. Present investigation of cooking rate constant will be useful in designing more efficient jam cookers with higher ratio of effective heating surface to batch volume of fruit pulp.

**Key words:** Cooking rate, pineapple bakery jam, rate constant, activation energy, batch volume

### INTRODUCTION

Pineapples (*Ananas comosus*) grow in some tropical countries such as Hawaii, India, Malaysia, the Philippines and Thailand. Pineapple varieties are plentiful, but only a few types are sold commercially, (Bartholomew *et al.*, 2003). Pineapple are vibrantly coloured with fabulous flavours and make fragrant jams and luxurious sweet preserves. These are made from fruit boiled with sugar until setting point is reached. They rely on pectin, sugar and acid for a good set, (Mayhew, 2008). In most countries there is a legal requirement to use a certain minimum amount of fruit material in the product if it is described as jam, but jellies may not have to contain any fruit base material (Manley, 2001).

The main constituent of fruit is water, which contributes about 78 to 88% of total weight; other volatile constituents, such as essential oils, esters, etc., are usually relatively negligible in quantity. The non-volatile constituents include sugars, fruit acids, pectin and gums, woody fiber and cellulose, nitrogenous substances, mineral salts and starch. Colouring matters, tannins, ascorbic acid and alkaloids may also be present in small quantities. In most fruits the natural sugars, sucrose, glucose and fructose constitute the greater part of the total soluble solids (Morris, 2004).

Fruit pulp, pectin, sugar and acid are contained in jam as it is an intermediate moisture food (Santanu *et al.*, 2007). Jam is a preparation consisting of whole fruit boiled with sugar, having a consistency firm enough to meet the demands of confectioners. All jams shall contain not less than

68.5% total soluble solids (Morris, 2004). Street (1991) stated that boiling fruit with sugar until the total soluble solids reaches 69.5% to produce jam, but for bakery purposes a stiffer jam of about 72% solids is often used. The solids content can be monitored using a refractometer (Street, 1991). Sugar is necessary to give the strength of the pectin-sugar-acid gel. It is assumed that about 3 to 5% of total weight of jam is represented by sugar derived from the fruit; meanwhile about 65% is added sugar (Morris, 2004). Sugar may be added to fruit or pulp either in solid form or dissolved in water as sugar syrup. Addition of solid sugar frequently causes a slight burning of the sugar, particularly on the surface of the boiling pans, resulting in the caramel flavour which is the characteristic of home-made jam (Rauch, 1965).

Sucrose acts as sweetener or a humectant which is a common ingredient of many food products (Troller and Christian, 1978). The main sources of sucrose are sugar cane and sugar beet, (Jones *et al.*, 1997). The main effect of particle size of sugar is to influence the rate at which the sucrose crystals will dissolve in water (Cauvain and Young, 2006). Sugar are generally very soluble in water and frequently form supersaturated syrups when their solutions are concentrated by boiling or evaporation (Coultate, 1992). Sucrose is a disaccharide which can be separated into a 1:1 mixture of glucose and fructose, known as invert sugar (Jackson, 1995).

In all jam and jelly boiling, the immediate indicators of the end point are thermometer and long handled, flat spoon or skimmer, made of silver or copper. When thermometer has risen to about 218 to 220° F, the jam is tested for jelling properties by dipping the skimmer into the boiling mass and observing the manner in which the jam or jelly falls from the edge. Firstly, it merely runs off in a stream, showing that the end point has not been reached. Later, it begins to thicken and finally it shows a tendency to gel by flaking off or breaking off clean. The practical tests are supplemented by tests in laboratory in order to determine the total solids and the degree of inversion of sugar in the jam. The thermometer and skimmer should be used continually throughout the day's run and the jam should be tested in the laboratory at frequent intervals (Morris, 2004).

During the boiling process, sucrose undergoes a chemical change. Sucrose is converted into two reducing sugars, which are dextrose and laevulose. They are known as invert sugar. There is no general standard of jam boiling. Almost every factory has its own process of production and develops its peculiar quality, yet there are certain factors applicable to all good quality jams, and it is these factors which should be stabilized. They are soluble solid content of jam, the sucrose-invert sugar balance of jam and pH of jam. The amount of invert sugar in jams should always be less than the amount of sucrose present. Based on total soluble solids of 70%, the percentage of invert sugar should be less than 35%. The inversion of sugar is affected by both the boiling time and boiling temperature (Rauch, 1965).

A short boiling time is of the utmost importance for the preservation of the colour and natural flavour of the jam. Excessive boiling greatly increases the inversion sugar. Important factors affecting boiling time are the ratio between the volume of the boiling pan and its effective heating surface, the heat conducting properties of the boiling mixture, the temperature of the heating surface and the steam pressure. During the process of boiling, part of the moisture content of the boiling mixture is evaporated. The larger the batch in the boiling pans in relation to the heating surface, the longer is the boiling time. The jam boiler's safest control to determine the end point is the weight of the finished product and its soluble solid content (Rauch, 1965).

In the present study, the reaction order of pineapple bakery jam cooking and activation of cooking process were examined. The effects of cooking temperature, stirring speed and batch volume on the cooking rate of pineapple bakery jam were investigated. The most suitable

temperature for cooking pineapple bakery jam was determined in order to produce the pineapple bakery jam with high cooking rate and the colour and favour will be accepted by public.

Earlier researchers have determined the degree of cooking by using different techniques (Chakkaravarthi *et al.*, 2008). Morris (2004) and Rauch (1965) stated that the total soluble solids of jam were measured from time to time to determine the end point of cooking. The total soluble solids will be increased from time to time as the moisture content of pineapple juice is evaporated during jam cooking process. The total soluble solids must be 72 or above for bakery jam in order to form a stiffer jam (Street, 1991).

In the present study, cooking rate was assumed to follow the first-order chemical reaction. In the first-order chemical reaction, the reaction rate constant, K can be expressed as:

$$-dC_A / dt = K C_A \quad (1)$$

Integrating on both sides with limits ' $C_{A0}$ ' to ' $C_A$ ' and time '0' to 't', we get:

$$-\ln (C_A / C_{A0}) = Kt \quad (2)$$

where,  $C_A$  is the concentration of A at any time t and  $C_{A0}$  is the initial concentration of A.

The cooking rate of pineapple bakery jam can be represented by increment of total soluble solids as the water is evaporated, thus, the total soluble solids of pineapple bakery jam at any time during the cooking process act as an indicator of degree of cooking. The rate of total soluble solids' increment represents the cooking rate and the Brix° was integrated in to Eq. 2, the equation can be written as:

$$-\ln[(B-B_0)/(B_f-B_0)] \quad (3)$$

where, B is the total soluble solids (Brix°) at any time t,  $B_0$  is the initial total soluble solids (Brix°),  $B_f$  is the final total soluble solids (Brix°) of cooked jam and K is the cooking rate constant.

In the present study, Eq. 3 has been used to examine the kinetic rate constants of the cooking process, as it is easier and suitable to govern the increment of total soluble solids of jam during cooking as it is an indicator of degree of cooking.

The temperature dependency from Arrhenius equation is shown in Eq. 4:

$$K = K_0 \cdot e^{-(E_a/R.T)} \quad (4)$$

Convert both side into logarithmic term, we get:

$$\ln K = \ln K_0 - (E_a/R).(1/T) \quad (5)$$

where,  $K_0$  is the pre-exponential, R is gas constant,  $E_a$  is activation energy and T is absolute temperature. This Eq. 5 has been used to obtain the activation energy,  $E_a$  of the jam cooking reaction by plotting graph of  $\ln K$  vs  $1/T$  and  $E_a$  is the value of slope gradient multiplied by negative gas constant, -R.

## **MATERIALS AND METHODS**

**Preparation of jam:** Ingredients for preparation of traditional pineapple bakery jam were fresh pineapple fruits and coarse sugar. Mayhew (2008) stated that the ratio of pineapple to sugar was 1:1. The fresh pineapple fruits (Moris cultivar) were purchased from Kompleks Pasar Borong in Seri Kembangan, Selangor, Malaysia. The granulated sugar was purchased from supermarket.

Firstly, the stalk and top of pineapple were cut off by using a knife and the cut base was placed on a board. Next, the skin was peeled while the 'eye' was removed (Mayhew, 2008). The peeled pineapples were blended into fruit pulp with a domestic blender (Philips Comfort H1720, Malaysia) and it was subsequently transferred into Ezy Cooker (Patent Pending No. PI 20070387) at lab of Department of food and process engineering, UPM which consists of a stainless-steel pot with hot oil jacket, rotating stirrer, temperature controller and stirrer speed controller. In this present study, sugar was added into the pulp before the cooking process with the ratio of 4:1 (20% sugar).

The cooking processes were operated at temperature of 70, 80, 90 and 100°C with each 3 L batch volume and stirring speed of 100 rpm. Next, the 3 L batch volume was conducted at temperature of 90°C with stirring speeds of 100, 80, 60, 40 and 20 rpm. Lastly, the cooking processes were conducted at temperature of 90°C and stirring speed of 100 rpm with 2, 4, 5 and 6 L batch volumes. The end points of cooking processes are reached when the Brix° of jams achieve around 76 to 77%.

**Total Soluble Solid (TSS):** Total soluble solid (TSS) or °Brix of pineapple bakery jam were examined with a Digital ABBA Refractometer (Model AR-2008, Kruss, Germany). The jam was placed on the equipment and the reading was recorded. The Brix° of jam was started to measure after the pulp inside the Ezy Cooker achieved the required cooking temperature. The cooked jam was measured in every 2 min until Brix° achieve the desired value. Each measurement was repeated thrice and the average value of these replications was calculated.

## **RESULTS AND DISCUSSION**

**Cooking rate curve of jam:** The relation between the Brix° of jam and the time of cooking at temperature of 90°C and stirring speed of 100 rpm is shown in Fig. 1. The rate of Brix° increment during the initial state was very low. The rate was raised from 16th minutes until 34th min. The rate was decreased during final state. The Brix° increased from time to time as the water is evaporated during cooking process.

During the initial state, the pulp is in the liquid form. The water on the surface can be only evaporated and the water molecules in whole liquid always compete for evaporating from surface. Rauch (1965) stated that the larger batch of pulp in boiling pan in relation to heating surface, the longer of boiling time. Thus, the rate was slow during initial state as the volume of pulp was largest at beginning state.

During the middle state, the pulp becomes semi-solid form. Thus, the surface area for evaporation is higher as it is constantly stirred. During the final state, the majority proportion of pulp is in paste form. Hence, majority of water molecules are bounded with the others molecules. Therefore, the inter-molecules forces between water and others molecules inside the jam create a strong resistance for water evaporation.

In this present study, the trend of cooking rate curves for all cooking temperatures and stirring speeds are identical with Fig. 1, but the difference between the curves are the final boiling time and

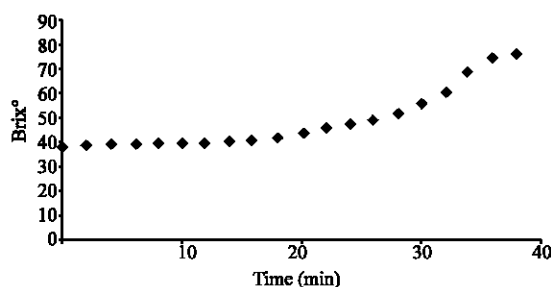


Fig. 1: Brix° Vs time for cooking temperature of 90°C

the cooking rate constant. The initial Brix° of pineapple liquid before cooking was around 38 to 39% and the final Brix° of cooked jam was around 76 to 77%.

**Effect of temperature on kinetic rate constant:** Figure 2-5 show the relation between the logarithmic total soluble solids gain ratios of jam and the cooking time for cooking temperature of 70, 80, 90 and 100 °C with stirring speed of 100 rpm. The linear relationship between the logarithmic total soluble solids gain ratios of jam and the cooking time showed that cooking rate followed the equation of first order chemical reaction. The kinetic rate constants, K for each cooking temperature were obtained from the values of slope gradient. The rate constants for cooking temperature of 70, 80, 90 and 100 °C were 0.06, 0.106, 0.133 and 0.207. The relation between rate constants, K and cooking temperature is shown in Fig. 6. Apparently, the rate constants, K of cooking processes increased with cooking temperature. Hence, the cooking rate of jam increased with cooking temperature as the kinetic rate constant was increased.

Figure 7 shows the relation between logarithmic rate constants and inverse of absolute temperature. The slope was gained from Fig. 7 was -5050 and it multiplied with negative gas constant, R, -8.413 J K.<sup>-1</sup> mol to get E<sub>a</sub>. Thus, E<sub>a</sub> of this cooking process was 42.49 kJ mol<sup>-1</sup>.

**Effect of stirring speed on kinetic rate constant:** Figure 8-11 show the relation between the logarithmic total soluble solids gain ratios of jam and the cooking time for stirring speed of 80, 60, 40, 20 rpm at cooking temperature of 90°C. The linear relationship between the logarithmic total soluble solids gain ratios of jam and the cooking time showed that cooking rate followed the equation of first order chemical reaction. The rate constants for stirring speed of 80, 60, 40 and 20 rpm were 0.12, 0.111, 0.104 and 0.077. The relation between rate constants, K and stirring speed is shown in Fig. 12. The rate constants, K of cooking processes increased with stirring speed since the stirring enhances uniformity of heat transfer inside the jam and stirring causes turbulence to the jam which increases kinetic energy of molecules inside the jam. Hence, the cooking rate of jam increased with stirring speed as the kinetic rate constant was increased.

**Effect of batch volume on kinetic rate constant:** Figure 13-16 show the relation between the logarithmic total soluble solids gain ratios of jam and the cooking time for batch volumes of 2, 4, 5 and 6 L at cooking temperature of 90°C and stirring speed of 100 rpm. The linear relationship between the logarithmic total soluble solids gain ratios of jam and the cooking time showed that cooking rate followed the equation of first order chemical reaction. The rate constants for batch volumes of 2, 3, 4, 5 and 6 L were 0.149, 0.133, 0.123, 0.102 and 0.079. The linear relationship

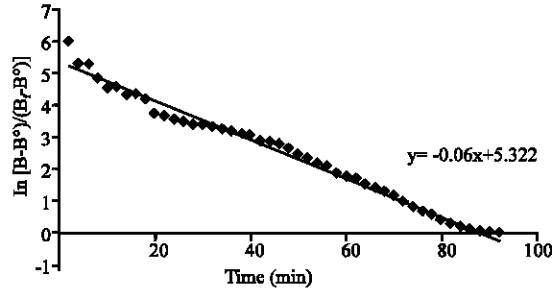


Fig. 2:  $\ln[(B-B_0)/(B_f-B_0)]$  vs. time for cooking temperature of 70°C

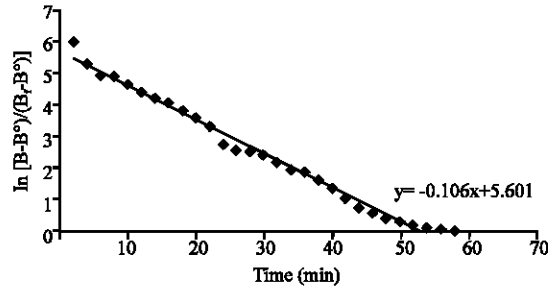


Fig. 3:  $\ln[(B-B_0)/(B_f-B_0)]$  vs. time for cooking temperature of 80°C

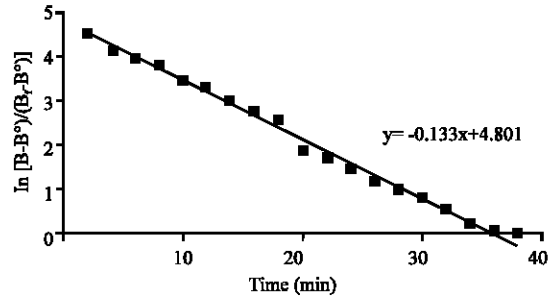


Fig. 4:  $\ln[(B-B_0)/(B_f-B_0)]$  vs. time for cooking temperature of 90°C

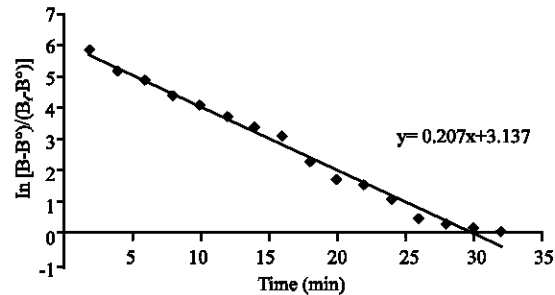


Fig. 5:  $\ln[(B-B_0)/(B_f-B_0)]$  vs. time for cooking temperature of 100°C

between rate constants,  $K$  and batch volume is shown in Fig. 17. The rate constants,  $K$  of cooking processes decreased with increasing batch volumes since the larger batch volume requires longer time to evaporate the water. Besides, the exposed surface of pulp to effective heating surface becomes lesser for the larger batch volume. Thus, the larger batch volume causes lower efficiency

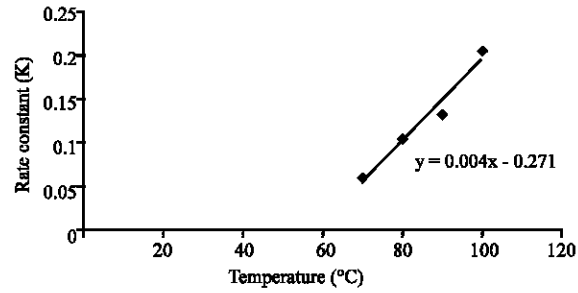


Fig. 6: Kinetic rate constant, K vs. temperature

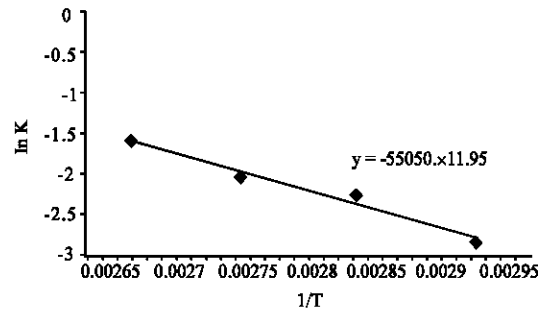


Fig. 7: ln K vs. 1/Temperature (1/T)

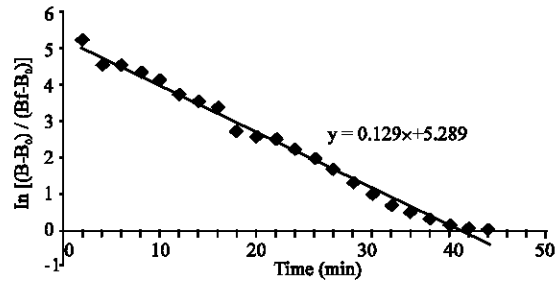


Fig. 8:  $\ln[(B-B_0)/(B_f-B_0)]$  vs. time for stirring speed of 80 rpm

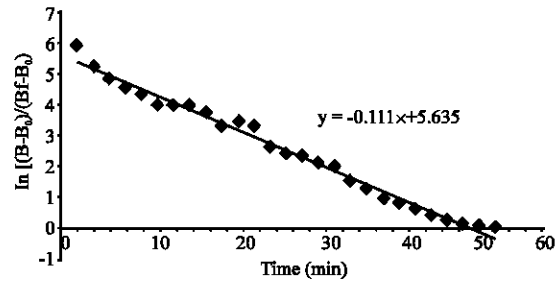


Fig. 9:  $\ln[(B-B_0)/(B_f-B_0)]$  vs. time for stirring speed of 60 rpm

and lesser consistency of heat transportation. Hence, the cooking rate of jam decreased with increasing batch volume as the kinetic rate constant was decreased.



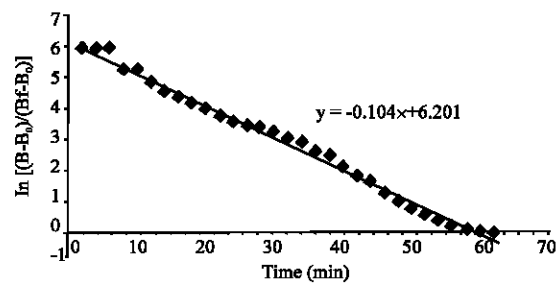


Fig. 10:  $\ln[(B-B_0)/(B_i-B_0)]$  vs. time for stirring speed of 40 rpm

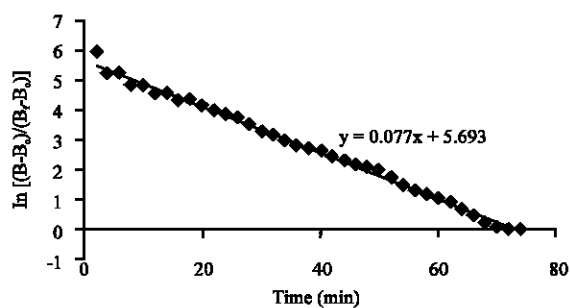


Fig. 11:  $\ln[(B-B_0)/(B_i-B_0)]$  vs. time for stirring speed of 20 rpm

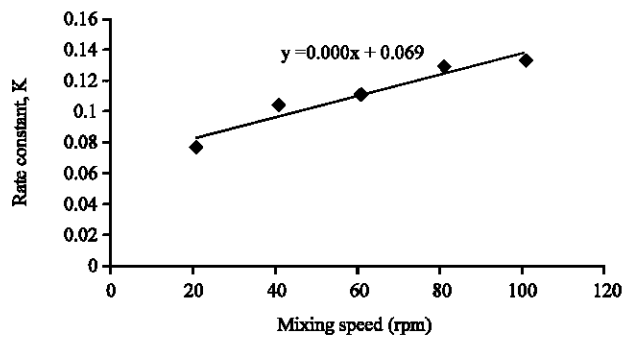


Fig. 12: Kinetic rate constant, K vs. stirring speed, rpm

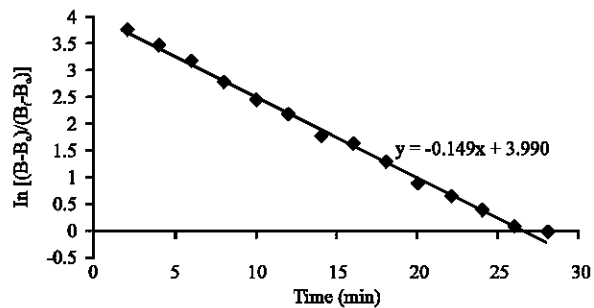


Fig. 13:  $\ln[(B-B_0)/(B_i-B_0)]$  vs. time for 2 liters batch volume

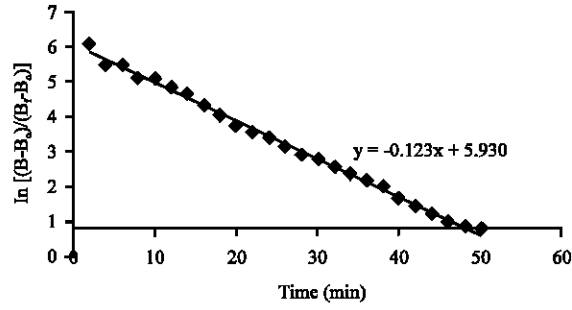


Fig. 14:  $\ln[(B-B_0)/(B_f-B_0)]$  vs. time for 4 L batch volume

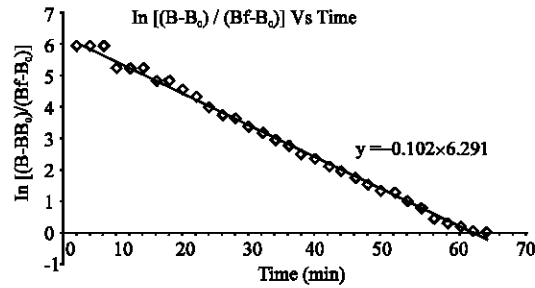


Fig. 15:  $\ln[(B-B_0)/(B_f-B_0)]$  vs. time for 5 L batch volume

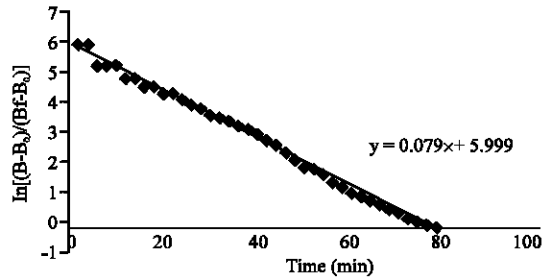


Fig. 16:  $\ln[(B-B_0)/(B_f-B_0)]$  vs. time for 6 L batch volume

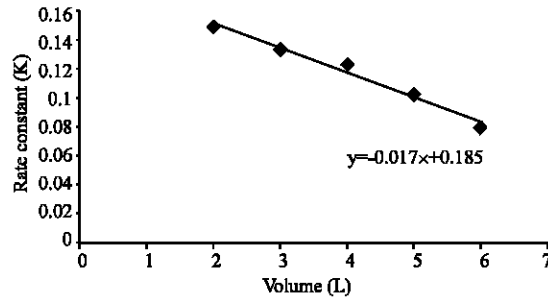


Fig. 17: Kinetic rate constant, K Vs batch volume

## CONCLUSION

Cooking rate of pineapple bakery jam followed the equation of a first-order chemical reaction. The rate constant increased with cooking temperature and stirring speed, but decreased with increasing batch volume. The cooking temperature of 100°C caused highest cooking rate, but the

jam was burnt at heating surface, thus, the darker colour and caramel favour were resulted in the jam. So, the recommended temperature for cooking pineapple bakery jam was 90°C in order to produce jam in high rate and the colour and favour will be acceptable by public. The effects of temperature, stirring speed and batch volume on cooking rate constant were investigated to provide a guideline and reference for designing a better jam cooker in aspect of heat transportation and higher cooking rate.

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