CHAPTER 2

Literature review

2.1 Longan

Longan (*Dimocarpus longan* Lour.) is an exotic subtropical fruit of the Sapindaceae family which is commercially grown in many countries, especially in Southeast Asia (Yang *et al.*, 2009). Longan fruit has gained approval as an outlandish fruit in the temperate zones, which is an appropriate fruit with strong acceptance by consumers on world markets because of its appropriate sweet taste and good benefits for health (Rangkadilok *et al.*, 2007 and Yang *et al.*, 2011). Longan has health benefits for consumers because longan fruit contains fiber, vitamins and antioxidant compounds (Table 2.1) such as its aril, seed and pericarp play a role as bioactive ingredients in many traditional Chinese medicines within different ways as improving women's health after parturition and pharmacological activities (Yang *et al.*, 2009).

2.2 Enzymatic browning of fresh – cut fruits and vegetables

The value of fresh – cut fruits and vegetables influences the customer's acceptance and is a grouping of parameters consisting of appearance (size, shape, and color), texture (firmness, crispness and juiciness), flavor (sweetness, bitterness and sourness) and healthy value (vitamins, minerals and fiber) (Suttirak and Manurakchinakorn, 2010). Color is one of the important factors which influences on the acceptance of consumers. Moreover, surface browning of fresh – cut fruits and vegetables is a fundamental attribute which also effect on the acceptability of the products. It can be caused by the action of two oxidoreductases enzymes which included polyphenol oxidase (PPO) and peroxidase

(POD). Polyphenol oxidase (PPO) and peroxidase (POD), which can be found in plastid and other organelle, come into contact with phenolic substrates that located in the vacuole, results in brown color (Yifen *et al.*, 2015).

Table 2.1 Nutritional composition of longan fruit

Composition	Nutrition value per 100g
Energy	251 kJ (60 kcal)
Carbohydrate	15.14 g
Dietary fiber	1.1 g
Fat	0.1 g
Protein	1.31 g
Thiamine (B1)	0.031 g
Riboflavin (B2)	0.14 mg
Niacin (B3)	0.3 mg
Vitamin C	84 mg
Calcium	1 mg
Iron	0.13 mg
Magnesium	10 mg
Phosphorous	21 mg
Potassium	26 mg
Proline	0.042 g
Leucine	0.054 g
Lysine	0.046 g
Valine	0.058 g
Alanine	0.157 g
Aspartic acid	0.126 g
Glutamic acid	0.209 g

Source: USDA Nutrient Database (2016)

All phenomena such as cutting, shock, loss of firmness leading to beginning of browning reactions which prompt alterations of flavor, odor and nutritional value. To avoid this phenomenon, various methods have been developed. These methods play roles in inactivation of PPO or avoiding contact between the enzyme and its substrate, in adding antioxidants or retaining the structural integrity of the food (Irina and Mohamed, 2013). In most cases, physical and chemical methods can control enzymatic browning. Physical methods consist of oxygen and/ or temperature reduction, using modified atmosphere packaging or edible coatings or treatment with gamma irradiation or high pressure (Olusola, 2002). Various physical methods such as edible coatings, modified atmosphere packaging and refrigeration have been applied to reduce enzymatic browning in fruit (Li *et al.*, 2015); the excellent semi-permeable film of chitosan/nano-silica can extend shelf – life, reduce browning index, and inhibit PPO activity in fresh longan fruit (Shengyou *et al.*, 2013). Chemical methods make use of compounds that play a role of inhibition the enzyme and removing its substrates (oxygen and phenols) or function as preferred substrates (Olusola, 2002). Using antibrowning agents to control the enzymatic browning is an effective and frequently employed method. The agents, which can act to antibrowning, can be divided into six groups consisting of acidulants, reducing agents, chelating agents, complexing agents, enzyme inhibitors and enzyme treatments, based on inhibitory mechanisms (Son *et al.*, 2001; Garcia and Barret, 2002; Altunkaya and Gokmen, 2009).

Ascorbic acid is a natural inhibitor of PPO. It prohibits significantly enzymatic browning, due to its ability is to reduce *o-quinones* back to their congenital phenols before they execute further reaction to form pigments, results in preventing the browning of sliced apple and extending its shelf life (Nadeem *et al.*, 2013). Previous research studied that sodium chlorite ($NaClO_2$), an oxidizing and sanitizing agent, inhibited enzymatic browning of 'Daw' longan fruit and extended storage life for a few days (Khunpon *et al.*, 2011); oxalic acid, a chemical compound, was a more potent anti-browning agent compared with other acids at 5% of concentration (Whangchai *et al.*, 2006) and combination of 0.4% citric acid and 1% calcium lactate could be achieved the best qualities of frozen strawberry (Magdy, 2014). Citric acid was used to pretreat whole longan fruits at 0.25% of concentration for storing the dried products at 25 – 30^{o}C (Attabhanyo and Teimpakdee, 1999) or immersing fruits in citric acid solution (1%)

earlier to drying method or osmotic dehydration was utilized to counteract enzymatic browning in fruits (Chavan and Amarowiez, 2012). In case for inhibition of surface browning of fresh – cut peaches, it could be done by dipping in an aqueous solution containing 1% ascorbic acid and 1% citric acid (Gabriela *et al.*, 2015).

2.3 Osmotic dehydration

Osmotic dehydration is one of the hypothetical preservation techniques which is truly a binding of dehydration and impregnation processes. This process may improve the value of the final products, modifying attractive new food products and saving potential energy (Shi and Xue, 2009). It is a process of counter – current transfer of mass, thus the solute runs into the food product and water is removed from the internal of the food to the hypertonic solution. When food materials are immersed in a concentrated osmotic solution which combined from one or more solutes, resulted in multi – component transfer process, in which solution flows simultaneously with a combination of drying, filtering and impregnation processes in the matrix of biological tissues. In the first few hours, the moisture loss from the product occurs quickly, and then the rate of moisture loss decreases slowly during next 6 hours (Ahmed *et al.*, 2016). The diffusion of moisture from food material rate reduces, the solute rate raises into the food material even through the dispersion of solute into the food might insignificant at the primary period of osmotic treatment (Ahmed *et al.*, 2016). Generally, the solution move out of food material, which is water mixed with solutes (minerals, flavor compounds, organic acids and reducing sugars), that influence the sensorial and nutritional properties of the final food products. Soluble solids, which exist in the osmotic solution, are occupied by the food material. Then, gas flow is also out of intercellular space (Shi and Xue, 2009). This phenomenon is shown in Fig. 2.1.

2.4 Application of osmotic dehydration in food processing

Osmotic dehydration effects on the qualities of fruits and vegetables such as physicochemical, nutritional and sensorial properties. Therefore, it has mostly been consume to progress new products in food processing (Ahmed *et al.*, 2016) such as taking full advantage of the ratio of sugar and acid; enriching the constancy of texture and pigments during drying and stored processes (Rastogi *et al.*, 2005). Most of the chemical, physical and biological activities, which get the foods worse, are ceased due to the osmotic treatment removes partly water, thus leading to intermediate moisture food product with lower water activity (Piasecka *et al.*, 2012). Moreover, osmotic pretreatment supplies benefits such as reducing process time, energy consumption and heat process which can damage to the flavor and color of final products, as well as retarding enzymatic browning (Khan, 2012). The process of osmotic has often been proposed as an initial stage in food processing and then followed by any kind of drying processes such as hot air drying, vacuum drying or freeze – drying. This process can be applied in processing of some dehydrated fruit and vegetable products such as confectionery products, yogurt, ice cream, desserts and some of dried products as snacks or components of cereals for direct usage (Torreggiani and Bertolo, 2001).

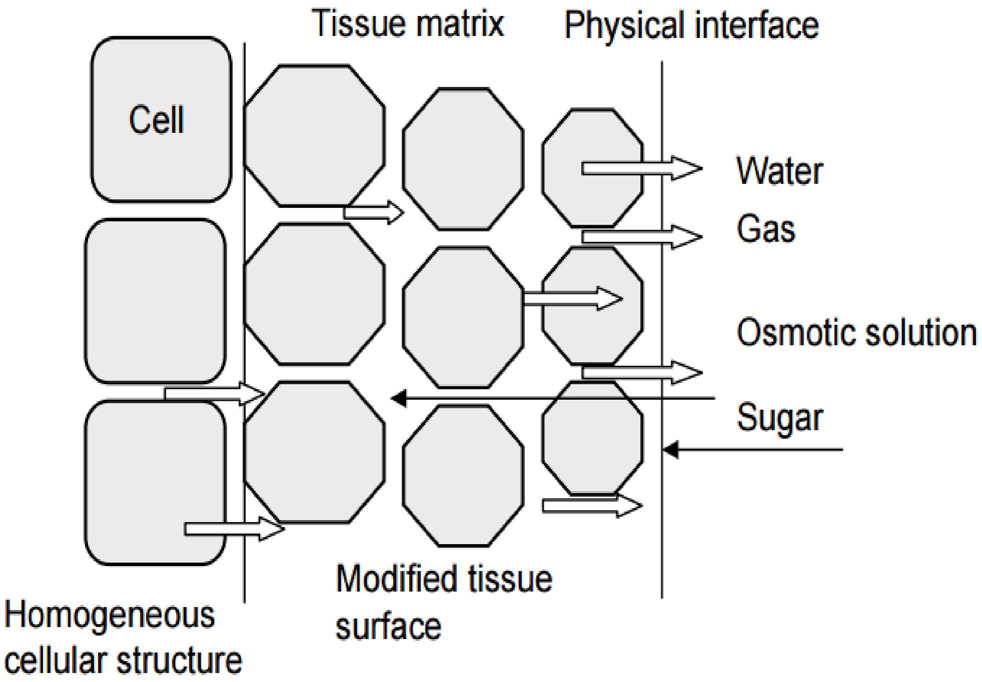

Figure 2.1 Schematic cellular material representation and mass transfer pattern

Source: Shi and Xue (2009)

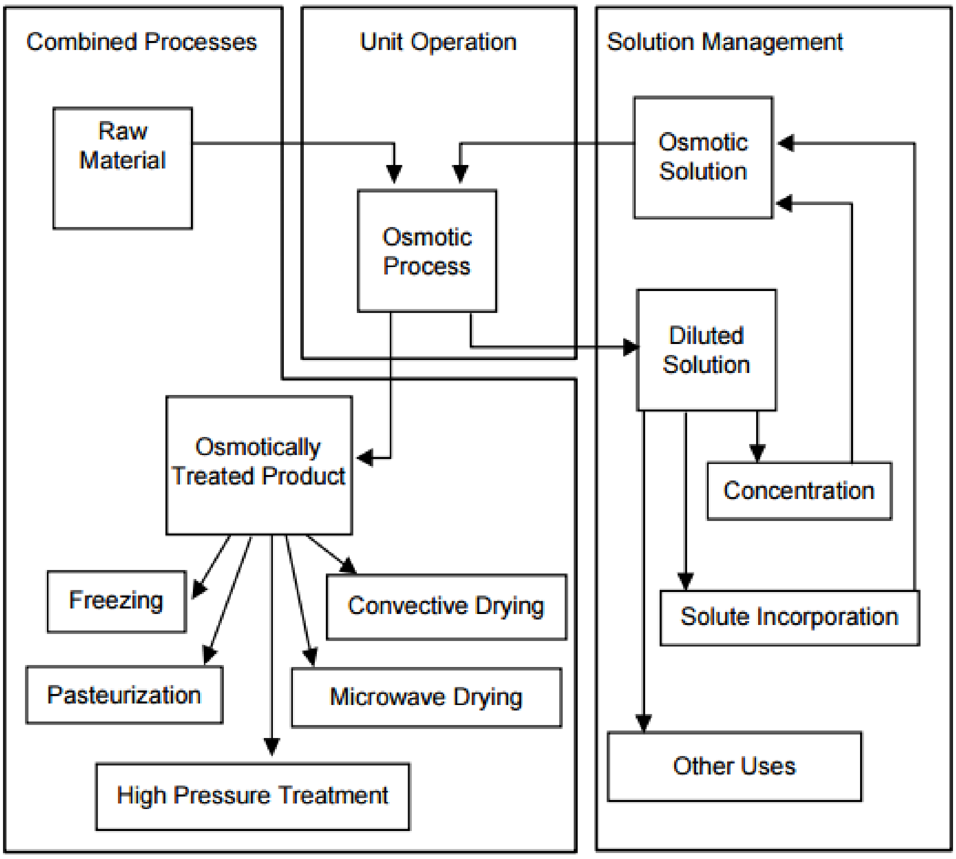

Fig.2.2 The potential industrial applications of osmotic dehydration

Source: Shi and Xue (2009)

Azoubell and Francinaide (2008) carried out the consequence of osmotic dehydration on mango fruit by varying the processing temperature in range of 30 to 50°C, concentration of solution in range of 40% to 60% w/w and the immersing time from 60 to 150 minutes. Hence an optimal mixture of sucrose solution (44% w/w), processing time (80 min) and a temperature of 38°C were optimized with maximum water removal (25%) with less than 6% solid uptake. In another study, the effect of osmotic dehydration on Andes berry (*Rubus glaucus* Benth.) and tamarillo (*Solanum betaceum* Cav., dark-red strain) fruit by immersing in different three osmotic agents which are sucrose (70%), sucrose + glucose (70% + 65%) and ethanol, resulted in the low of water activity and the elution of flavor constituents and anthocyanin into the osmotic solution (Osorio *et al.*, 2007). Ponting *et al.* (1966) reported that the combination of osmotic dehydration and either frozen, air drying or vacuum drying processes illustrated a 50% weight reduction of apples. The apple products had superior quality without using sulfur dioxide treatment.

Thus, the effortlessness of the osmotic dehydration without using of expensive equipment and requirements for less or no energy could be proper for large – scale fruit preservation (Shi and Xue, 2009). The probable industrial applications of osmotic dehydration are given in Fig. 2.2. And numerous industrial applications of osmotic dehydration on fruit processing and preservation are provides in Fig. 2.3 (Shi and Xue, 2009).

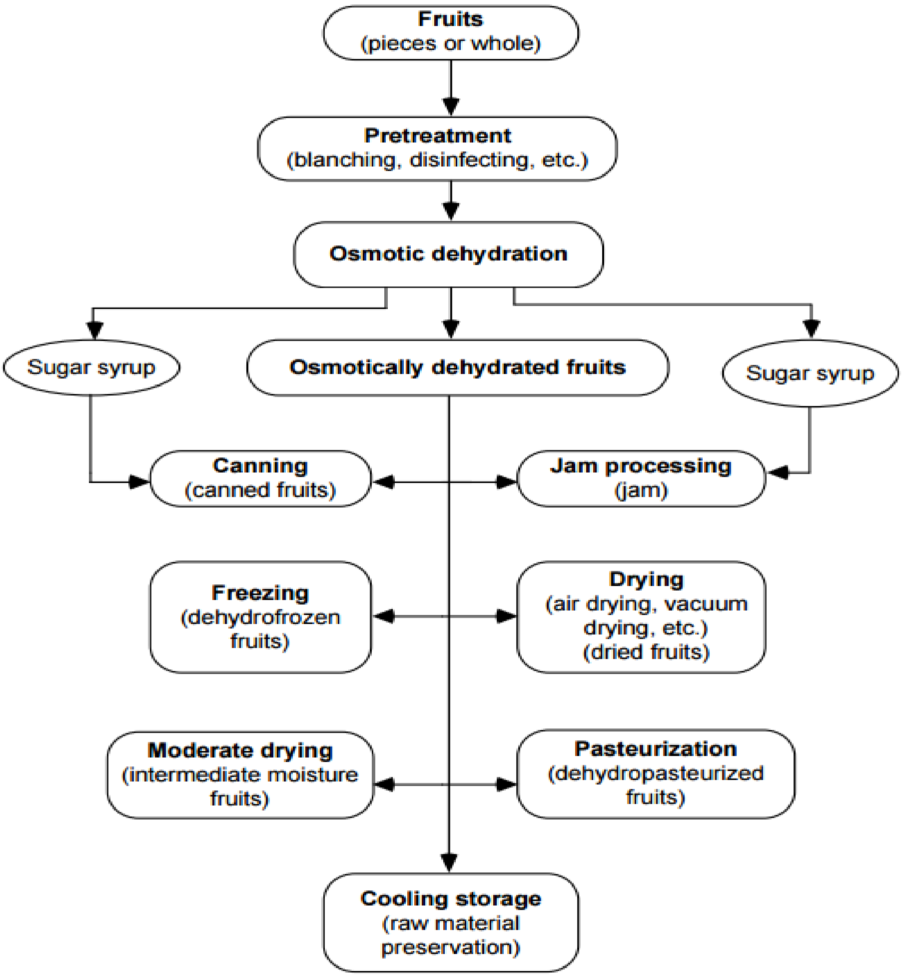

Figure 2.3 Various industrial applications of osmotic dehydration on fruit processing and preservation

Source: Shi and Xue (2009)

2.5 Factors affecting osmotic dehydration process

Variable features, which could influence on the mass transfer during osmotic dehydration process, are variety, pretreatments, maturity, temperature and concentration of osmotic agent, geometry of the material, agitation, and food pieces to osmotic solution ratio, additives, physicochemical properties and structure (Khan, 2012; Raoult-Wack, 1994; Torreggiani, 1993). The factors are followed as:

Firstly, numerous studies have been researched that blanching, sulfating, alkaline dipping, application of high hydrostatic pressure and freezing have been used earlier to osmotic dehydration process as the pretreatment method which could reduce the detrimental variations in biological material due to the conventional drying techniques (Ade-Omowaye et al., 2001; Pokharkar, 2001). Tadesse et al. (2015) reported that the combination of blanching and osmotic pretreatment and then further drying processing of carrot slices resulted in enhanced nutritional quality and sensorial acceptance. Papaya and mango slices were received a high acceptance when combination of pretreatment with sulfur dioxide or blanching prevents discoloration of food materials and osmotic dehydration process. The osmotic solution were the mixture of ascorbic acid (0.4%) solution and the mixture of ascorbic acid (0.4%) and KMS (0.1%) solution for 30 minutes (Torreggiani, 1993). Moreover, dipping food materials in citric acid solution (1%) and hence applying osmotic dehydration could prevent enzymatic browning which occurred on fresh – cut fruits and vegetables (Sunjka and Raghavan, 2004).

Secondly, the physicochemical properties, molecular weight, solubility and ionic state of osmotic agent might influence on the osmotic dehydration process (Lazarides, 1994 and Lenart, 1992). Penetration of osmotic agent with lower molecular into the cells of fruits and vegetables is easier than that of osmotic agent with higher molecular (Phisut, 2012). Besides, the pH of osmotic solution can affect on texture of food product as the pH decreased (pH 2) the texture of the apple became softer. Because of the depolymerization and hydrolysis of the pectin, the firmness of the product should be in a range of pH 3.0 – 6.0 (Tortoe, 2010). Therefore, glucose, sucrose, glycerol, sorbitol and fructo – oligosaccharide are commonly used. The impacts of various osmotic agents are shown in Table 2.2. The lowest and the highest water losses were found by sorbitol and sucrose solutions while the lowest and the highest solid gains were obtained by fructose and maltodextrin solution during the osmotic treatments of apricot fruit, respectively (Ispir and Toğrul, 2009). Hence, fructose and sucrose solutions are regarded as the best in osmotic dehydration of apricots because they resulted in low solid gain and high water loss.

Thirdly, the mixture of osmotic agent also affects on the osmotic dehydration process by the mass transfer kinetic (Ahmed et al., 2016). The concentration of osmotic solution increases the greater rate of water loss was indicated until the equilibrium level was achieved (Lenart, 1992 and Tortoe, 2010). As well as, Tortoe (2010) reported that less concentrated sucrose solution conducts to minimal loss of water and solid gain ratios. Falade et al. (2007) studied about varying concentrations of sucrose solution (40 ^{o}Brix, 50 ^{o}Brix and 60 ^{o}Brix) on the osmotic mass transfer of water melon slabs, resulting in the watermelon slabs treated with higher osmotic solution concentration were found to higher of the water loss and solid gain. Likewise, Mundada et al. (2011) studied the effect of numerous sucrose concentrations (40 ^{o}Brix, 50 ^{o}Brix and 60 ^{o}Brix) on the mass transfer of pomegranate arils during osmotic dehydration, resulting in pomegranate arils immersed in 60 ^{o}Brix sucrose solution indicated higher solid gain and water loss than others.

In addition, process duration also affect on the osmotic dehydration. It can be seen clearly that the increase in immersing time could lead to higher loss of moisture of food products during osmotic dehydration (Ispir and Toğrul, 2009; Mundada et al., 2011). To maintain the concentration of the solution constant, the immersion time was increased which related in the increase of water loss, but the rate of increase was decreased (Chavan and Amarowiez, 2012). According to Chavan and Amarowiez (2012), the optimization of duration of osmosis process represented that the water loss took place at the maximum rate within the first 2 hours of the osmosis treatment. However, Gudapaty et al. (2010) reported that Indian gooseberry should be immersed in 40% sucrose solution for 12 hours to improve their qualities after blanching stage. This process is classically requested on fruits which consist of pineapple, mango, papaya and lychee in order that the taste can be enhanced and structural characteristics can be maintained during drying processing (Patchimaporn et al., 2015).

Next, temperature is the most critical factor which influences on the mass transmission rate of osmotic dehydration (Tortoe, 2010). The temperature, which affects on the kinetic of moisture loss without exposing any impact on solid gain, is more noticeable between 30 and 60^{o}C for vegetable and fruits (Pokharkar, 2001). Lazarides (1994) studied the higher sugar gain (up to 55%) was obtained by apple processed at a temperature of 30 and 50^{o}C compared to the ambient temperature condition. It can be explained that the permeability of the membrane is enhanced by the swelling of membrane and plasticizing effect. However, the temperature which is higher than 60°C can damage the plant tissues (Ramaswamy, 2005).

Table 2.2 Different osmotic agents and their effects on osmotic dehydration process.

Osmotic agents	**Effectives**
Sucrose	- Reduces browning by preventing oxygen entrance - Provides stability to pigment - Retains volatile compounds
Corn syrup solution	- The values of solid gain and water loss of samples dehydrated in corn syrup solution are lower than that obtained from the samples processed in sucrose solution. Due to the corn syrup solution had higher viscosity and molecular weight than sucrose.
Salt	- Hinders oxidative and non – enzymatic browning - Provides the driving force for mass transfer - Hinders the surface shrinkage - However, it has limited to use in fruit processing because of its salty taste.
Ethanol	- Decreases the viscosity and freezing point of osmotic solution in cooling and freezing processes. - Achieves the lower water activity of the product - Enhances the shelf – life stability of the product
Fructo - oligosaccharide	- Leads to lower diffusion rate compared to that of sucrose because the molecular weight of fructo – oligosaccharide is higher than that of sucrose.
Maltose	- It showed simultaneously higher water loss and lower sugar gain during osmotic dehydration than sucrose solution

Source: Ahmed *et al.* (2016)

Finally, the sample weight to solution ratio is one major importance, which affects the mass transfer during the osmotic treatment of fruits and vegetables. The optimum ratio which was suitable for practical is 1:2 or 1:3 (Ahmed et al., 2016) and 1: 1 (Wangcharoen, 2009).

2.6 Drying technology

The crucial method for preserving of fruit product is drying or dehydration which is defined one of the oldest and easiest methods of food preservation (Renee and Karleigh, 2009). Dehydration is the process of taking away water or moisture from a food product. Decreasing the moisture content of food can prevent the spoilage – causing microorganism growth and make enzymatic reactions slowly take place within food. Moreover, removing moisture from foods makes them smaller and lighter; ease to handling during storing, packaging, transporting and using. Dried foods are the best choice for backpacking, hiking and camping because their weight takes much less than the non-dried foods and they do not need refrigeration. Moreover, drying food is also a good way of preserving seasonal food for later use (Renee and Karleigh, 2009). Hot air drying is a simple and common method on fruits and vegetables drying processing (Orikasa *et al.*, 2014). Several studies have investigated the hot air drying could be applied in fruit and vegetables with a high moisture content such as tomatoes, apples, sweet potatoes and kiwifruit (Orikasa *et al.*, 2005, Sjoholm and Gekas, 1995; Orikasa *et al.*, 2010 and Orikasa *et al*., 2014). Moreover, study of drying kinetics with varied temperatures from 55°C to 85°C by Aree *et al.* (2001) and Tippayawong *et al.* (2009) recommended that 65°C hot air drying can be applied to produce the desired golden brown peeled longan and at 60°C by Rithmance and Intipunya (2012) in pretreatment of dried longan by a hot air dryer. Chaikham *et al.* (2013) also applied temperature of 60°C for drying flesh longan by hot air oven. However, hot air drying has some limitations such as low energy efficiency and long processing time. Besides, it also degrades significantly color and nutrient of food products (Orikasa *et al*., 2014). Vacuum oven is another type of dehydration in which materials are dried in a reduced pressure environment with lower needed heat for rapid drying (Parikh, 2015). It has some distinguishing characteristics compared with conventional drying. Vacuum drying process can help food sample prevent the oxidization reaction due to the material has no contact with air during the drying process. Therefore, the foodstuffs were effectively maintained the sensory and nutritional qualities when the short drying time and low drying temperature were applied in the drying process (Wu et al., 2007). Mathematical models, which described the moisture content changes during the hot air drying and vacuum drying of sliced kiwifruits, were designed by Chen et al. (2001), Orikasa et al. (2008) and Orikasa et al. (2012). The qualities of kiwifruits changed during hot air drying and vacuum drying have been stated. Hence, an ideal drying condition for a more wholesome and high – quality dried product was established.

2.7 Dehydration kinetics

The drying kinetics of food product, which include mathematical modelling and simulation of the drying curves, are the most important tool in dryer's design, donating to a better understanding of the drying mechanism and to obtain high quality product (Meisami – asl et al., 2009, Revaskar et al., 2014 and Ratti, 2009). It can be seen clearly that a product dehydrates under specific drying condition by drying kinetics which are influenced by the exterior states of the medium and the chemical and physical structure of the food (Ratti, 2009). The moisture content of a food material is obliged to determine as a function of time which obtain the dehydration kinetics curve. The moisture content (X) is estimated on a dry basis as the ratio of the amount of water in the sample to the amount of dry solids such as the following equation:

$$X = \frac{m - m_s}{m_s}$$

Source: Ratti (2009) (2.1)

Where m is the total mass of the food material at time t and m_s is the mass of the dry solids. The equation 2.2 gave the correlation among moisture content in dry and wet basis.

$$X_w = \frac{X}{1 + X}$$

Source: Ratti (2009) (2.2)

Where X_w is the water content on a wet basis. A typical drying kinetics curve with the moisture content as a function of drying time was illustrated by Fig. 2.4. In figure 2.4a, section a – b is the start – up stage, in which the product can contact with the medium and heats up. Accurate process occurs during section b – e. The solid leads to equilibrium with the medium condition after long drying times and no further drying takes place at point e. The free moisture content (X_f) which is available in food material for drying can thus be calculated as

$$X_f = X - X_e \qquad \textbf{Source}\text{: Ratti (2009)} \qquad (2.3)$$

Where X_e is the equilibrium moisture content.

Next, Fig. 2.4b illustrates the drying rate as a function of time, which represents the same points as those in Fig. 2.4a. The drying process can be described in a number of steps which characterized by different dehydration rates under constant conditions. It can be usually occurred in 2 dehydration periods such as *an initial constant rate period* (section b – c) at which drying happens if clean water is being melted away, and one or several *falling rate periods* (section c – d and d – e) in which the combination of external – internal resistances can control the movement of moisture (Ratti, 2009).

During the constant rate period, the surface of the product is saturated with water and heat is transferred to the product from air. The wet bulb temperature of the drying air is used as the product temperature. In this stage, the drying rate is self – determining of the material surface and estimated by the exterior conditions. Besides, a period, in which the rate of drying gradually reduces following the constant rate period, is called the falling rate period. The point which is at the ending of constant rate period and beginning of the falling rate period is called the point of critical moisture content (X_c). It is indicated by point c in Fig. 2.4b which represented in the drying rate curve as a sharp change of shape. In the falling rate period, either a combination of external and internal mechanism or internal mass transfer can control the movement of moisture on foodstuffs. It can be summarized that the drying rate of any of these periods are influenced by the heat and mass transfer coefficients, diffusion coefficients and the outward drying states (Ratti, 2009).

Moreover, to select an optimum model for describing the drying process of foodstuffs which is essential to predict and simulate the drying behavior, the drying curves are fitted with several thin – layer drying equations (Table 2.3).

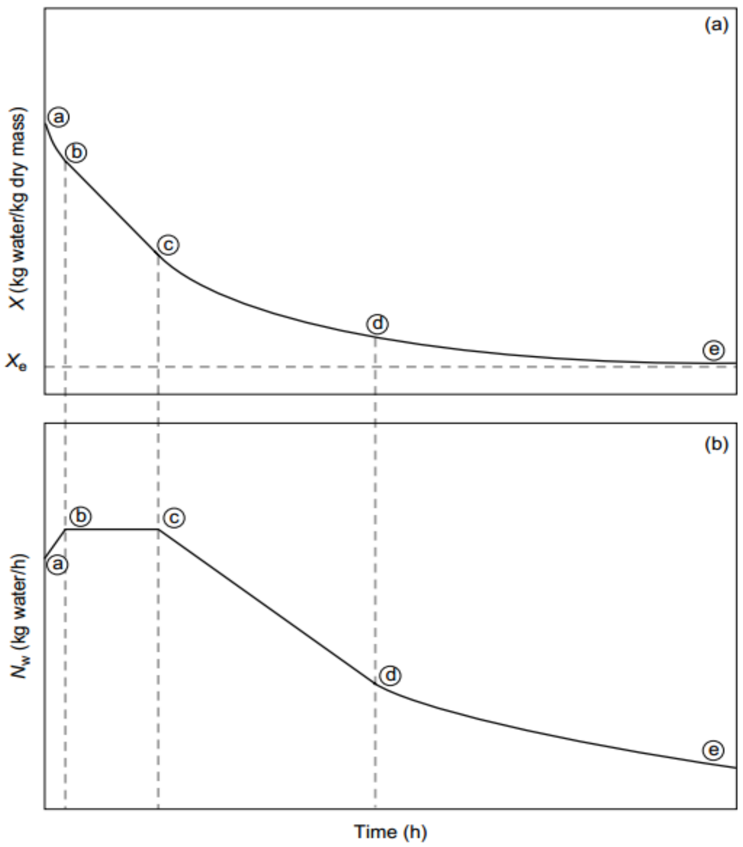

Figure 2.4 Drying curves as a function of drying time: (a) drying kinetics and (b) drying rate

Source: Ratti (2009)

Nonlinear regression analysis was carried out using Excel and statistical parameters of coefficient of determination (R^2), root mean square error (RMSE) and reduced Chi square (χ^2) are evaluated between the mathematical models and examine the validity (Fernando and Amarasinghe, 2016). The coefficient of determination (Eq. 2.9) is a primary criterion used to recognize the best fit. Besides that, the root mean square error (RMSE) and reduced χ^2 can also be used to determine appropriateness of the fit (Sarasavadia et al., 1999) (Eq. 2.10 and 2.11). For the quality fit, R^2 should be close to 1, even as the values of the RMSE and reduced χ^2 should be close to zero (Fernando and Amarasinghe, 2016).

Table 2.3 Mathematical models applied to drying curves of samples

No.	**Mathematical models**	**Equations**		**Constant**
1	Exponential	$MR = exp\ (- kt)$	(2.4)	k
2	Henderson & Pabis	$MR = a\ exp\ (- kt)$	(2.5)	a, k
3	Logarithmic	$MR = a\ exp\ (- kt) + c$	(2.6)	a, k, c
4	Page	$MR = exp\ (- kt^{n})$	(2.7)	k, n
5	Power law	$MR = at^{b}$	(2.8)	a, b

Source: Revaskar et al. (2014)

Where *MR* is moisture ratio, *t* is time (s) and *k*, *a*, *b*, *c* and *n* are constants.

$$R^2 = \frac{\sum(MR_{exp} - MR_{pre})^2}{\sqrt{\left[\sum(MR_{exp} - MR_{pre)}\right]^2 * \left[\sum(MR_{exp} - MR_{pre)}\right]^2}} \qquad (2.9)$$

$$RMSE = \left[\frac{1}{N}\sum(MR_{exp} - MR_{pre})^2\right]^{1/2} \qquad (2.10)$$

$$\chi^2 = \frac{\sum(MR_{exp} - MR_{pre})^2}{N - n} \qquad (2.11)$$

Source: Revaskar et al. (2014)

Where MR_{exp} and MR_{pre} are the experimental and predicted moisture ratios respectively, *N* is the total number of observations and *n* is the number of constant in the model.

The residuals for each modelling are plotted to determine if a pattern exists. The models that provide the lowest value for RMSE and the residuals plots with randomly scattered points are considered to be the best fit for a given sorption isotherm (Ian and Kevin, 2013). Furthermore, the mean relative deviation E% (Eq. 2.12) was also used to evaluate the goodness of the fit that gives a clear idea of the mean divergence of the estimated data from the measured data. Lomauro et al. (1958a, b) and Gencturk et al. (1986) studied that value of E% smaller than 5.0 represents an extremely good fit; a value between 5.0 and 10 indicates a reasonably good fit; and a value greater than 10 illustrates a poor fit.

$$E(\%) = \frac{100}{N} \sum \left| \frac{Experimental\ value - Predicted\ value}{Experimental\ value} \right| \qquad (2.12)$$

2.8 Packing and storage stability of osmo – dehydrated product

Most of fruits and vegetables could be made reachable throughout the year by overwhelming the problems of oversupplied seasons. Ahmed *et al.* (2016) reviewed that the exceptional quality air tight containers and food evaluation cans are used for packaging of osmo – dried foods which can inhibit moisture absorption from the atmosphere and other contaminations. On the others, aluminum foil and a high – density polyethylene pouches, laminated polypropylene pouches are suggested for packing of intermediate moisture products (Sagar and Khurdiya, 1999; Ahmed and Choudhary, 1995). Furthermore, a considerable cost reduction in the packaging and distribution of osmo – dehydrated food could be probable to reduce volume and weight of product and lead to easier in handling and transportation processes (Biswal *et al*., 1991).

The stable shelf - life of osmo – dried products fluctuates from six months to one year (Chavan and Amarowicz, 2012). The previous studies reported the storage of osmotically dehydrated papaya products stored unchanging up to six months at the ambient temperature (Ahemed and Choudhary, 1995) and banana products were stored up to one year or more depending on the storage conditions and packaging materials used (Bongirwar and Sreenivasan, 1977). Sudhanshu *et al.* (2009) reported that the intermediate moisture pineapple slices were stored during 40 days at atmosphere temperature with good texture, color and sensory acceptability. The main factor which was concerned for the improvement of osmo – dehydrated food products is the microbial load. It may affect on the shelf – life of packaged products (Castelló *et al*., 2009). Therefore, it could be seen clearly that microbes can be efficiently controlled by a suitable combination of water activity and pH in food (Tiganitas *et al.,* 2009). Derrickson-Tharringtona *et al*. (2005) studied *Escherichia coli* in dehydrated apples could be inactivated by pretreatment with acid solutions. It has been widely accepted that the use of citric acid in different types of cut fruits can reduce effectively the surface pH (Soliva-Fortuny and Martín-Belloso, 2003). Furthermore, the water activity is a major parameter which related with the shelf – life of osmo – dehydrated products. It is defined as the available moisture content in food product (Ahmed *et al.*, 2016). Different levels of water activity indicated different microbes' growth. The osmo – dehydrated product is in a range of water activity 0.6 – 0.84 and equivalent to moisture content of 20 – 40%. So, Spoilage of this group food product is concentrated to osmophiles, microorganisms growing in high sugar concentrations from 65 – 70% and tolerating low pH values ($pH < 0.4$). The most common spoilage agents are osmophilic yeast such as *Saccharomyces* and *Torulopsis spp* which makes a fermentation of the sucrose, resulting in the production of alcohol. Since osmophiles are heat – sensitive and can be killed readily during heat processing, so spoilage of these products is only possible after recontamination. This reason may occur through sealing or after opening the containers (Hayes, 1992).

2.9 Prediction of shelf – life

There are many different definitions of shelf life such as "the shelf life of a food is the time period for the product to become undesirable from sensorial, nutritional or safety perspectives" (Fu and Labuza, 1993); "the shelf life of a food is the time between the production and packaging of the product and the point at which it becomes unacceptable under storage conditions" (Ellis, 1994); and the IFST Guidelines (1993) defined that the shelf life is a period in which the food product still ensure safety, maintain desired sensorial scores, chemical, physical and microbiological parameters under the recommended conditions. Abundant changes occur in foods during processing and storage because foods are perishable by nature. It is well known that the quality attributes in foods are influenced by the condition which used to process and store foods (Man and Jones, 1994). Nowadays, food producers challenge with a strong pressure to develop new products in record time along with improving productivity, shelf life and overall quality. Therefore, certain key modes of food deterioration, which are expressed mathematically as rate equations, could be examined.

The major modes of food deterioration include (1) environmental impacts such as temperature, light, humidity and oxygen which can generate several reaction mechanisms that may lead to food degradation; (2) physical changes, which are caused by abusing of foods during harvesting, processing and distribution, lead to a reduced shelf – life of foods; (3) chemical alterations, which involve the internal food components and the exterior environmental elements, may cause food deterioration and reduce food's shelf life and (4) microbiological changes, which were determined to influence on shelf – life of foods (Man and Jones, 1994). To evaluate the shelf – life of a food, Kwolek and Bookwalter (1971) suggested to use the chemical kinetic approach to model changes in food quality. In 1980, Saguy and Karel promoted to use the kinetic approach and the Arrhenius relationship that can be used to predict the effect of temperature on the reaction rate constants and then the value of the inactivation energy of food quality deterioration from shelf life data at known temperatures was developed by Lai and Heldman (1982).

A overall form of kinetic model is acquired by considering the following chemical reaction

$$aA + bB \overset{k_f}{\underset{k_b}{\leftrightarrow}} cC + dD$$

Where A and B are reactants, C and D are the products, and *a, b, c* and *d* are stoichiometric coefficients for the reactants and products, and k_f and k_b are forward and backward for the reactants and products. The rate of reaction in which a reactant (for example reactant A) changes would be given by

$$-\frac{\mathrm{d}\,[A]}{\mathrm{d}t} = k'_f\,[A]^n \qquad (2.13)$$

Where k'_f is the peuso forward rate constant, and n is the reaction order. The concentration of a species described mainly the rate of reaction because it is difficult to determine the actual mechanisms of the intermediate reactions that lead to a particular change in quality of food (Man and Jones, 1994).

A general rate expression would be written as follows for a quality attribute Q

$$\pm\,\frac{\mathrm{d}Q}{\mathrm{d}t} = kQ^n \qquad (2.14)$$

Where ± refers to either decreasing or increasing value of the attribute Q, *k* is the peuso forward rate constant, *n* is the observed order of reaction. The environmental factor such as temperature, humidity and light and concentrations of other components, which are kept constant, is assumed (Man and Jones, 1994).

2.9.1 Zero order reaction

A quality attribute Q which decreases during the storage time as shown in Fig. 2.5, is considered. The linear plot illustrates that the rate of loss of food's quality attribute is constant throughout the storage period and it may not be influenced by the concentration of Q, therefore substituting n = 0 in equation (2.15) (Man and Jones, 1994)

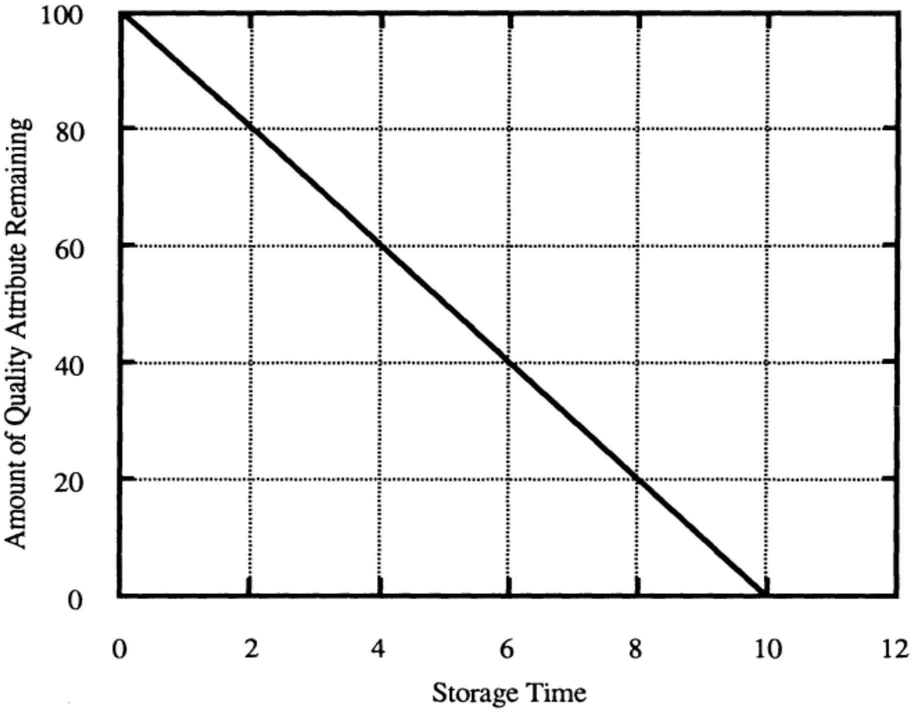

Figure 2.5 Decrease in a quality attribute of a food during storage (zero order reaction)

Source: Man and Jones (1994)

$$-\frac{\mathrm{d}Q}{\mathrm{d}t} = k \qquad (2.15)$$

Equation (2.5) may be integrated to obtain

$$Q = Q_o - kt \qquad (2.16)$$

Where Q_o illustrates some initial value of a quality attribute and Q is the amount of that attribute left after time t. And the quality attribute reaches to a certain level Q_e at the end of shelf – life (t_s)

$$Q_e = Q_o - kt_s \tag{2.17}$$

Therefore, the shelf life *(t_s)* may be defined as

$$t_s = \frac{Q_o \; - \; Q_e}{k} \tag{2.18}$$

The zero order rate equation (2.15) can be used in describing some reactions as enzymatic degradation, non – enzymatic browning and lipid oxidation that leads to change of rancid flavors (Man and Jones (1994).

2.9.2 First order reaction

This exponential plot between quality attribute and time states a first order reaction with n = 1 (Fig. 2.6) and equation (2.15) is altered and integrated as follows,

$$-\frac{\mathrm{d}Q}{\mathrm{d}t} = kQ \tag{2.19}$$

$$ln\,\frac{Q}{Q_o} = -kt \tag{2.20}$$

And the shelf life *(t_s)* may be calculated as

$$t_s = \frac{ln\,\frac{Q_o}{Q_e}}{k} \tag{2.21}$$

The first order rate equation (2.19) can be used in describing some reactions of losses such as vitamin and protein losses and microorganism growth (Man and Jones (1994).

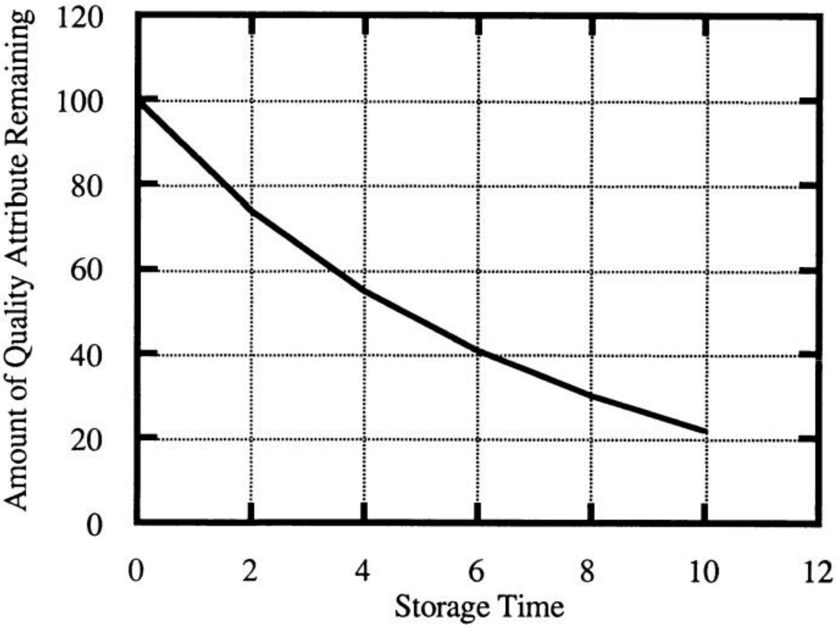

Figure 2.6 Decrease in a quality attribute of a food during storage (first order reaction)

Source: Man and Jones (1994)

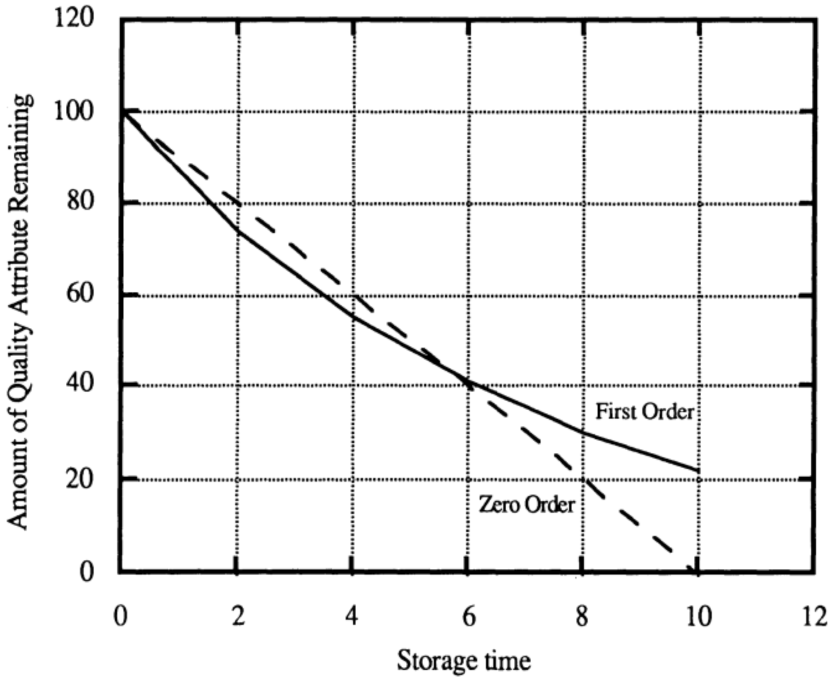

Figure 2.7 Decrease in a quality attribute of a food following two different orders of reaction

Source: Man and Jones (1994)

In addition, there are 2 important issues in investigating experimental data on rate of change of a given quality attribute. Firstly, the analytical exactitude of measuring attribute level influences on the value of rate constant. Secondly, the change in reactant species observed. Thus, two plots which include zero order reaction and first order reaction, are shown in Fig. 2.7. in this circumstance, the overlap of zero order and first order plots, which is up to about 55% reduction of the quality attribute, illustrates that either zero or first order model can be used to express the change of food's attributes. If the experimental data on the rate of change of a quality attribute are beyond 55% reduction, it means the zero order and first order models can be predicted. However, less than 55% reduction, there is a considerable difference in the level of quality attribute expected by a simple zero order reaction (Man and Jones (1994)

2.9.3 Arrhenius equation

Arrhenius relationship is used to describe the influence of temperature on the reaction rate, as follows

$$k = k_o \, exp\left[-\frac{E_a}{RT}\right] \tag{2.22}$$

Where E_a is the activation energy, R is the ideal gas constant, k_o is the pre – exponential factor and T is the temperature (Kelvin). Fig. 2.8 illustrates the temperature dependence of the reaction rate (Man and Jones, 1994).

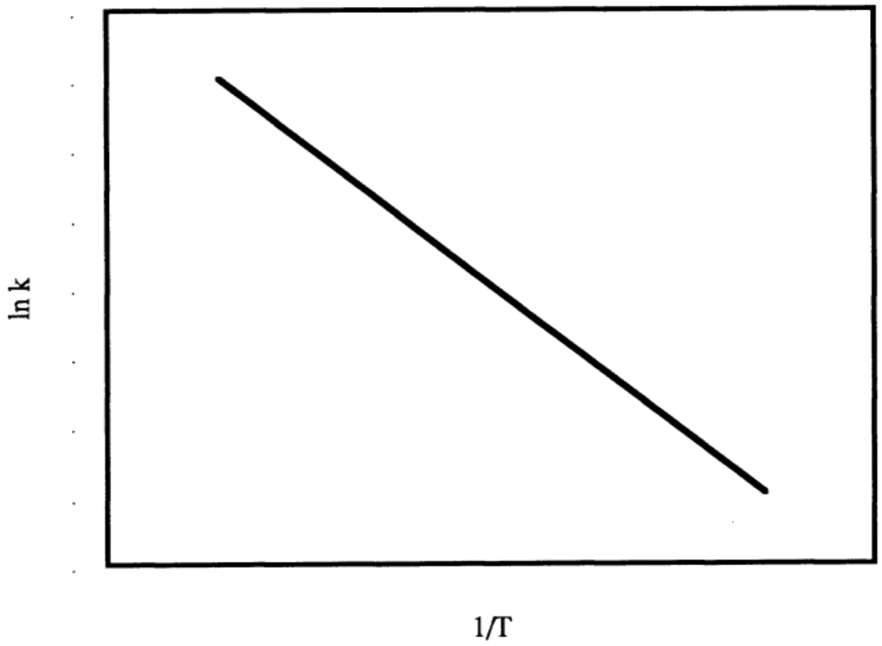

Figure 2.8 Influence of temperature on the reaction rate constant. Slope = E_a/R

Source: Man and Jones (1994)

Instead of using Arrhenius equation to describe the relationship between temperature and reaction rate constant, the Q_{10} also is used as follows

$$Q_{10} = \frac{reaction\, rate\ at\ temperature\ (T + 10)^{o}C}{reaction\, rate\ at\ temperature\ T^{o}C} \tag{2.23}$$

Source: Man and Jones (1994)

2.10 Sensory evaluation

Sensory evaluation is stated as a scientific method used to call up, measure, analyze and interpret reactions to those characteristics of foods and other materials to the used of human senses such as sight, smell, taste, touch and hearing for the purposes of evaluating consumer products (Stone and Sidel, 1993). General requirements and conditions for sensory tests should be concerned such as testing area, lighting, time of day, carriers, temperatures of samples, sample sizes, number of samples, coding, and palate cleansers (Hough, 2010). There are three main types of testing such as discrimination, descriptive and hedonic or affective test methods (Lawless and Heymann, 1998). Firstly, the discrimination is a method which based on the statistics of frequencies and proportions (counting right and wrong answers) and would be conducted with 25 to 40 participants. Secondly, the descriptive test is a method that quantify the perceived intensities of the sensory characteristics of a product. The panel for this test might consist of 10 to 12 well – trained individuals who went through the training and were oriented to the meanings of idiom and well practice with samples. The final major class of sensory tests is hedonic or affective test method. The 9 – point hedonic scale usually used to assess liking and disliking (9 = “like extremely”, 5 = “neither like nor dislike”, 1= “dislike extremely”). 75 to 150 panelists who were regular users of this product would be used in this test (Lawless and Heymann, 1998).