INVESTIGATING THE EFFECT OF PRE-TREATMENT ON THE DRYING KINETICS AND QUALITY TRAITS OF RICE NOODLES

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Dedicated to Ismail Abu Bakar and Rohani Abu Bakar

ABSTRACT

Rice noodle has long been a very common food to most East Asians. Moreover, the overwhelming trend towards gluten-free food which introduces positive health beneficial effects has currently promoted rice noodle throughout the world. In spite of that, fresh rice noodle is truly perishable and prone to degradation within several days. Therefore, there is an urgent need to produce the good preservation of high quality fresh rice noodle of a good textural and cooking quality with an adequate shelf life. Therefore, the shelf life of rice noodle will be prolonged by the means of drying. Unfortunately, there is a lack of research on the processing aspects to produce better quality of dried rice noodle.

Indeed, this research focused on three key areas which include pre-treatment, drying processes, and quality parameter. Pre-treatment was performed by fully rinsing the rice noodle in distilled water to represent the low-fat noodle defined as non-oil coated sample in the study as compared to the original noodle. These two types of rice noodles were then subjected to three drying methods which were hot air drying, heat pump drying and freeze drying. The dried noodles were then subjected to the quality analysis including texture, colour, microstructures, fat content, starch gelatinization, rehydration ratio, and sensory evaluation. In addition to that, the transparency phenomenon was further described through physical inspection, colour analysis, and starch gelatinization.

The pre-treatment slightly reduced the drying time and increased the effective diffusivity. The effective diffusivities resulted for the first falling rate of non-oil coated and original rice noodle subjected to hot air drying at 30 °C are 1.60×10^{-11} m^2/s, and 1.25×10^{-11} m^2/s, respectively. The effective diffusivities obtained for the second falling rate of the respective non-oil coated and original rice noodle at 30 °C are 2.20×10^{-11} m^2/s, and 1.71×10^{-11} m^2/s. The effective diffusivities resulted for the first falling rate of original rice noodle at 60 °C and 90 °C are 6.35×10^{-11} m^2/s and 1.26×10^{-10} m^2/s respectively. The effective diffusivities obtained

for the second falling rate of original rice noodle at 60 °C and 90 °C are 7.59 x 10^{-11} m^2/s and 1.18 x 10^{-10} m^2/s respectively.

This is in agreement to the effective diffusivity obtained in the heat pump drying of rice noodles. The effective diffusivities resulted for the first falling rate of non-oil coated and original rice noodle subjected to heat pump drying at 38 °C are 7.75 x 10^{-11} m^2/s, and 5.59 x 10^{-11} m^2/s respectively. The effective diffusivities obtained for the second falling rate at 38 °C for non-oil coated and original rice noodle at 38 °C were respectively at 2.431 x 10^{-11} m^2/s. The effective diffusivities obtained for the first falling rate period of respective non-oil coated and original noodle are 1.14 x 10^{-10} m^2/s, and 1.05 x 10^{-10} m^2/s respectively. The effective diffusivities obtained for the second falling rate at 50 °C give straight lines for the non-oil coated and original rice noodle were respectively at 9.575 x 10^{-11} m^2/s and 8.78x 10^{-11} m^2/s.

Most quality attributes of rice noodle subjected to hot air drying and heat pump drying were declining which eventually led to the best quality preservation by freeze drying. In conjunction to that, transparency phenomenon can be clearly described through several quality analysis of rice noodle subjected to hot air and heat pump drying. Apparently, transparency phenomenon in rice noodle due to hot air and heat pump drying was deduced to have a more stable shelf life due to low microbial growth. After analysing the overall quality performance, heat pump drying at 38 °C is deemed as a convenient drying method in producing comparatively good quality attributes of dried rice noodle.

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HAD	hot air drying
HPD	heat pump drying
UV	ultraviolet
FD	freeze drying
SEM	scanning electron microscopy
DSC	differential scanning calorimetry
D_0	diffusivity
D_{eff}	effective diffusivity
MR	moisture ratio
RMSE	root mean square error
R	relation correlation co-efficient
R^2	co-efficient of determination
X^2	reduced chi square
X_I	moisture content
M_{ds}	dry solid weight
M_i	weight at time i
N	rate of water evaporation
A	evaporation area
M_s	bone dry solid weight
M_e	equilibrium moisture content
L*	light dark spectrum
a*	green-red spectrum
b*	blue-yellow spectrum
ΔE	total colour change
φ	heat flow rate
β	heating rate
C_p	heat capacity
T_0	temperature at which gelatinization starts
T_p	at peak gelatinization temperature
T_c	at which gelatinization ceased
ΔH	heat enthalpy
ANOVA	analysis of variance

CHAPTER 1

INTRODUCTION

1.1 RICE NOODLES

Noodles are characterized based on processing procedure, salt used, noodle width, and raw material, in which noodles may come in various contents, formulations, and shapes (Hou 2010). Noodles have been the staple food for most Asian countries since centuries due to the abundance of main crops like rice and wheats. Noodles can either be produced from rice, buckwheat, wheat, or starches that derived from potato and sweet potato. Unfortunately a systematic scheme in classifying Asian noodles has not been established and accepted by the noodle industry yet due to the very large gaps in noodle varieties among countries.

Indeed, fresh rice noodle of high quality should be uniform and straight strands, white and translucent shading, superior texture with the absence of broken strands, excellent cooking quality as well as adequate shelf life (Ahmed et al. 2016). Its main ingredients are rice flour and water but sometimes starch is introduced to increase the chewy texture or to maintain the noodle freshness (Sandhu et al. 2010). Normally available fresh either in strips or sheets from wet market, the noodle however may be cut according to different specifications.

Rice noodle which was previously consumed only by the Chinese can now be savoured by everyone as their daily meals (CNN 2011). In fact, rice noodle can be found anywhere across Asia from China to Thailand with different names and formulations. In Malaysia then, rice noodle is popularly known as *kway teow.*

Rice noodles are usually sold at room temperature which is deemed as the best condition to store them fresh. Unfortunately, they have a very short shelf life due to microbial spoilage at room temperature as they turn mouldy within several days (Rachel T. 2015). In order to store the noodles for a slightly longer period of time, the effect of microbial growth on the noodles can be minimized by freezing.

Despite storing in the refrigerator might be the convenient solution to most people, the method has somehow subjected the noodle to be under high moisture. This eventually incurs water-soluble nutrient losses include water-soluble polysaccharides, vitamins, minerals, free sugar, amino acids, protein (albumin) and fat towards shelf life. Furthermore, it contributes to the noodle aging which makes it harder and less cohesive. This has resulted the refrigerated noodle to be discarded as food wastes once its quality deteriorates.

Due to that, this persistent occurrences contributing to the wastage of rice noodle has eventually secured an opportunity for noodle drying. Food drying has resolved most of the food wastage issues which has become serious these days. The shelf life of noodles may be further extended by removing the moisture from the medium through the means of dehydration. Indeed, the importance of noodle drying is supported by the increasing production volume of dried processed food by 3.65% and sales growth of 7.07% and dried noodles by the increased production volume of 4.39% and sales growth of 11.08% (Nations et al. 2012).

1.2 NOODLES DEHYDRATION PROCESSING

Drying is a mass transfer process to remove water or moisture primarily from a solid, semi-solid or liquid through evaporation which shall cater as a final step before packaging. The process usually involves a source of heat or a medium in a way to remove the vapour produced since the absence of water inhibits bacterial growth that generally spoils the food. Drying has been deemed to be an efficient method for the preservation of most products which in turn increases product's shelf life. Moreover, it cuts down packaging cost in regards of shipping load and preserves its physical outlook, retains original essence and its nutritional values subjected to a proper dryer type and appropriate operating conditions (Fu 2008).

People from the early generations totally lived by nature like sun and water. Thus, this has given the idea for them to preserve the food under the sun as the convenient method especially in remote area so that the food may last longer. The sun drying of fruit and vegetable has been practised by generations for yesteryears to preserve for leaner times. Sun drying or the modified presently to be known as solar drying reduces the moisture up to 8-10%. However, this drying process is ruined with contamination issues like insect, dust, sand particles and soil. Furthermore, it depends on mostly sun light which usually affects the drying time to be very long.

In conjunction to that, sun drying must not be performed in the early morning since morning dew and overnight high humidity incurs the condensation of moisture to the product. Therefore, the optimum time to perform sun drying is during sunny day in particular the afternoon. However, the presence of rain will rapidly cool the dryer which resulted in a moisture film on the cover due to condensation. It will only be back to normal function again as the sun breaks through the following day (Mnkeni et al. 2008).

In the first few hours of sun drying, the product dries at the rate that moisture condenses on the inside of the plastic covers. Such occurrence can be reduced by keeping the loading gate to be slightly ajar just to allow the circulation of air. The noodle slices *(mi siput)* should dry within 1 to 2 full days depending on the weather (Mamat et al. 2016). Then, the slices should therefore be tested. A test for total dryness is normally conducted for particular different products. The insufficiently dried slices will turn moldy in a short time at room temperature whereby further drying should be allowed for another 1 or 2 hours before testing again.

Though recent advancement has brought changed perspectives on this traditional sun drying, the elevating concern for healthy and low cost-preservation techniques has put sun drying back to the fore as an environmentally-friendly alternative for the product preservation. Since then, the medium and small scale industries have adopted the traditional method of sun drying to preserve the food based products. However, when it comes to larger scale production, the product quality is the core business whereby the sun-dried product is of poor quality due to grit and dirt of the unpredictable weather. The presence of invisible microorganisms and excessive sunlight cause the product to be unhygienic and instable in chemical structure.

Therefore, state-of-the-art drying facilities are available with the ability to control temperature and velocity which generally preserve the overall product quality better. Despite removing moisture in the drying process prevents microbial spoilage to further prolong the shelf-life, an intensive care is required during the process to preserve possibly as much the nutritive value, cooking quality as well as natural flavour. It is worth to note that the purpose of drying is merely to extend the product's shelf life by closely preserving the fresh product quality. Due to this, drying process is only suitable to be subjected to the fully-ripened products so that the product quality may only degrade considerably (Brady 2017).

The traditional method for dried instant noodles adopts the drying temperature in the range between 35 ºC and 50 °C. In conjunction to that temperature, a proper drying takes up the whole day which sometimes is up to two days, depending on the product sample. The design of noodle drying equipment should meet the requirement of particular dry noodle manufacturer demands. Therefore, a reliable data on the drying characteristics of noodle is required. Indeed, the design of a good noodle dryer should reduce the drying time (Mamat et al. 2016).

Therefore, several types of dryers have been identified in regards to the subject of study which is rice noodle. As generally practised to most dried products, the conventional industrial processing method of rice noodles has always been hot air drying. The operating temperature is between 50 °C and 70 °C. Hot air drying is also typically applied in the production of steamed noodles and instant noodles. In particular, hot air drying at 50 °C is normally used in producing dried plain noodles (Fu 2008).

In hot air drying, surrounding air is continuously heated and circulated by the in-built fan to increase the driving force for heat transfer where moisture evaporates. By reducing the relative humidity, it builds up the driving force for the dehydration process. In the falling rate period, as the moisture content decreases, noodle surface heats up, and the moisture diffusion from the core of the noodle to the external layer is reduced (Ratti 2001).

In industrial food processing practice, short drying time is always desirable. Depending primarily on the drying method, drying time may be very long for several products. Such longer drying time for hot air drying definitely leads to the high energy consumption which contributes to high operating cost (Tirawanichakul et al. 2012)

Generally, drying the food products at high temperature requires shorter drying time than that of low temperature. Thus, the average drying rate at high temperature is relatively high compared to that at low temperature. Despite of short drying time, hot air drying however induces deterioration in product quality such as shrinkage, puffing, crystallization. High temperature drying is found to predominantly exert huge effects on colour and texture degradation. In fact, high temperature of hot air drying defines the declining of nutrients profoundly.

In addition, hot air drying may also lead to chemical or biochemical reactions which in turn affect its colour, odour, texture, and other properties of the solid product in a severe manner. The dehydrated products obtained from hot air drying are generally suffering from poor rehydration ability and colour degradation. Discolouration and browning are the common effects of pigment destruction during hot air drying. Moreover, the intention of obtaining shortest drying time by implementing excessive drying conditions for such product merely over-dehydrate the product surface thoroughly. This has eventually caused extreme shrinkage of pores, which is known as noodle declines which clearly not desired in most drying cases (Ratti 2001).

The varied product mishaps due to hot air drying have triggered the needs to produce a drying method of a much better product quality. Therefore, heat pump drying has been introduced in the industry to perform the drying process at a lower cost which has been proven to produce a product of better quality (Chin & Law 2010; Adapa et al. 2002a; Pal et al. 2008). It is able to dry wide-ranging products at a lower temperature. Recently, heat pump dryers have gained attention for being the energy-efficient and economically viable drying equipment for the production of good quality products.

Heat pump drying consists of a heat pump system and a drying chamber. The main components of the heat pump drying system are compressor, condenser, heat exchanger, evaporator, and a drying chamber with the refrigerant to transport heat. Indeed, the implementation of heat pump technology may primarily saves energy with the ability to run at lower humidity. Using a heat pump dryer, both the sensible heat and latent heat can be retrieved from the exhaust air, so that the overall thermal performance is improved. The total energy savings of approximately 40% were reported when utilizing heat pump dryers (Goh et al. 2011)

The heat pump drying is appropriate for high value products with the ability to produce controlled transient drying parameters such as humidity and temperature. The technology has been reported to better preserve the quality attributes in addition to the drying cost reduction. The low drying temperature in heat pump drying improves the bioactive ingredients and the physical properties of salak fruit (Ong & Law 2011).

Low temperature drying in heat pump drying has been proven to produce better product quality than the conventional high temperature drying. Therefore, the lowest temperature which is sub-zero temperature drying is introduced as the dried product quality control parameter to the study which is freeze drying. Freeze-drying is the most gentle drying process whereby moisture removal occurs by the principle of sublimation under a vacuum. After freezing, the water contained inside the product becomes ice and it goes through sublimation whereby frozen ice moisture escapes directly to the gaseous state at a very low pressure. At the sublimation line, ice sublimes which starts at the external layer of the product to form a porous dried material. The ice condenser condensed the vapourized moisture as the water discharge (George & Datta 2002).

The ability of freeze drying to preserve the colour, bioactive ingredients and food structure is widely recognized. Freeze-dried products are distinguished by high quality properties for instance high porosity, low bulk density, aroma retention, and superior than that of products produced by using other drying processes. By preserving its initial shape and dimension, the rehydration ability of freeze dried product is deemed to be satisfactory. In addition, freeze dried products are also better in terms of texture, shape, appearance, taste, colour, flavour, and viability of nutrients.

However, a very long drying time eventually leads to extremely high energy consumption which in turn increases the operating costs. This is credited to the very slow mass and heat transfer mechanism which is subjected under vacuum. Freeze drying is deemed to be economically viable only in producing high value products when protection of functional components in a product is desired as well as high priced vegetables like mushroom or capsicum. Unfortunately, freeze drying is not economically feasible in food processing industry because of the high operating and maintenance costs (Babić et al. 2009).

In this research, hot air drying is chosen as the drying method to represent the common industrial drying practice of rice noodle. In this regards, 60 °C is primarily chosen between the industrial temperature of 50 °C and 70 °C which is expected to be the best hot air drying method for rice noodle apart from other drying temperature. In the meanwhile, heat pump drying is introduced to observe the drying performance of rice noodle subjected to low temperature by implementing heat pump technology. Furthermore, freeze drying is in use as a control method to make freeze drying which is known as the best quality preservation as the reference in order to learn the quality preservation of rice noodle subjected to hot air and heat pump drying.

1.3 PROBLEM STATEMENT

Due to the fact that rice noodles in Malaysia are usually available in fresh form in wet market, they are perishable and therefore always results in wastage. The quick spoilage resulted mostly from the microbial activity. Therefore, it is no surprise that statistics from Solid Waste Corporation of Malaysia (SWCorp) reported that 15 million kilogrammes of food are wasted by Malaysians per day as their daily meal leftovers whereby 1 million kilogrammes are noodles (Norimah et al. 2008). This includes 3 million kilogrammes of food that is still fit for consumption to feed up to two million people three times a day whereby food wastes accounted to 45% from the total solid wastes (Naidu 2017).

The increasing awareness towards low fat diet these days has made rice noodle favourable. However, fresh rice noodles are usually covered with palm oil for the smoother packaging purpose as well as preventing quick spoilage during transportation and storage at room temperature. Therefore, the idea of pre-treatment is introduced in this research in order to represent non-oil coated rice noodle. In this regard, a layer of oil on the surface of the rice noodles is no longer needed as dehydration is supposed to be an efficient way to inactivate microbial activity. By achieving this, it is possible to penetrate the market of dried rice noodles in providing consumers the low fat diet option.

In conjunction to previous argument, drying of fresh rice noodle is truly the finest solution in reducing food wastage. In this case, there is a need to find out the optimum process parameters in order to produce the dried rice noodles by closely preserving its quality (Lewicki 2006). In conjunction to that, the studies of product quality of dehydrated rice noodles produced by different drying methods are performed. In addition, the study also aims to further explain the occurrence of transparency phenomena in high temperature drying of rice noodles. The assessment of such phenomenon may hopefully assist the noodle manufacturers in considering available drying options in the future.

1.4 OBJECTIVES

The objectives of the study on the drying performance of rice noodles were:

- To evaluate the drying kinetics of hot air drying and heat pump drying of rice noodles
- To evaluate the effects of pre-treatment on the drying kinetics of hot air drying and heat pump drying of rice noodles
- To evaluate the significance of hot air drying, heat pump drying and freeze drying on dried noodle quality.
- To investigate the transparency phenomena in hot air drying and heat pump drying of rice noodle as the limiting factor to be the best method in preserving the quality of rice noodle.

1.5 SCOPE OF RESEARCH

1.5.1 Pre-treatment

The effect of pre-treatment on dehydrated rice noodles quality was investigated. The pre-treatment was carried out by subjecting the rice noodles to rinsing.

1.5.2 Drying Kinetics

Pre-treated and non-treated rice noodles were dried under constant air conditions by using a laboratory oven (30 °C, 60 °C, 90 °C) and using a pilot scale heat pump dryer (38 °C, 50 °C). The moisture reduction was monitored throughout drying. The effects of pre-treatment on the quality of rice noodles and drying kinetics were studied in each drying method. Drying kinetics were then determined based on the drying curves.

1.5.3 Food Evaluation

Sensory evaluation was performed by examining the rehydrated rice noodles from different drying conditions. The evaluation was assessed in terms of colour, surface smoothness, textural smoothness, elasticity, oil/fat appearance, and taste.

1.5.4 Dried Product Quality

The dried samples by hot air and heat pump drying were then analysed in terms of texture, fat content, colour, microstructures, starch gelatinization, and rehydration ratio. All samples were also subjected to sensory evaluation study. The results were compared with reference to freeze drying samples. The texture of the dried samples was measured in terms of hardness of the sample. The colour was measured in terms of L^*, a^*, b^*, chroma value, and total colour change.

Meanwhile, the starch gelatinization was measured in terms of gelatinization temperature and rehydration ratio was calculated as the ratio of rehydrated noodle per dry weight of prior sample. The fat content was taken as the percentage of the extracted fat per sample weight and the microstructures were observed by the porosity. Comparison was made against published literature values.

1.5.5 Transparency Phenomenon

Preliminary studies showed that drying the rice noodles using some convective drying may lead to transparent dehydrated rice noodles. On the other hand, freeze drying produces opaque whitish dehydrated rice noodles. This study investigated the transparency phenomenon of rice noodles by looking at the physical appearance, L^* values in colour analysis, and glass transition of the dehydrated rice noodles subjected to different drying techniques.

1.6 SIGNIFICANCE OF RESEARCH

The present studies on the drying kinetics of rice noodle help to provide an insightful understanding on the mechanism of moisture transfer. Drying curves under various drying portfolios examined in the study may enable the prediction of drying rate and efficiency under a range of drying parameters.

The study of product quality in this research could determine the best drying method for rice noodle. In addition to that, the study of low-fat option to rice noodle in this research contributes to the increasingly growing healthy food market. Therefore, the effects of low-fat noodle which is described as non-oil coated noodle in comparison to the original noodle towards drying kinetics and product quality may benefit the noodle market in specific and the food industry as a whole.

Moreover, further analysis on the quality attributes of rice noodles could explain the transparency phenomena in different types of drying methods which eventually determines the best drying procedure to closely preserve fresh rice noodle. Apart from providing the degradation characteristics of rice noodles, the research serves as a good guideline to help decide in considering such occurring phenomena in food industry. In fact, in-depth knowledge in drying and quality degradation characteristic of rice noodles enables the design of appropriate drying equipment for rice noodle.

CHAPTER 2

LITERATURE REVIEW

2.1 NOODLES

Noodle was believed to originate from the harvested wheat in China in the early 5000 BC, and eventually spread to other neighbouring Asian nations (Hou & Kruk 1998). In fact, 40 % of the wheat flour consumption in Asia is for noodle manufacturing (Fu 2008). In present, the preference of having Asian noodles has also become likely to increase in many countries. The interest in noodles is well supported by the skyrocketing instant noodles market in that period of time. In 2013, the sales of instant noodles in Chinese mainland is more than 46.2 billion packets which makes up 52% of global consumption as according to the World Instant Noodles Association (Park et al. 2011).

In specific to a report released in 2015, Malaysians consume 3.6 million packets of instant noodles a day, of which accounted to 511 million packets per year and the demand of 1.34 billion packets of instant noodles in 2014 (Ngui 2015). Since the instant noodles market in Malaysia recorded a growth of 7.2% from 2010 to 2017, thus we shall witness a continuous growth of 5.5% until 2022 (Mordor Intelligence, 2016). Unfortunately, the sales of instant noodles by 2016 had drastically dropped to just 38.5 billion packets whereby the instant noodle companies are hugely affected. This has resulted Tingyi, one of the giant noodle manufacturer to sell its noodle factories in Xi’an this year.

Due to the convenient of food delivery which offers a much more proper meal in addition to the growing middle class has resulted instant noodles to be hardly welcomed by particularly East Asia (The Straits Times, 2017). However, the decreasing market for instant noodles does not affect the dried noodles. This is supported by the fact that noodle is listed as the top 10 weekly food among Malaysians in 2008, by not taking instant noodles into account (Norimah et al. 2008). This is due to the fact that dried noodles shall cater as the solution to the perishable fresh noodle wastage. Moreover, the National Health and Morbidity

Survey conducted by the Malaysian Ministry of Health has revealed that the intake of both dried and fresh noodles to be the second highest after white rice (Aris et al. 2014).

However, noodles are often consumed in soup and sometimes they are fried together with other local recipes. Asian noodles are not made solely from wheat as many are made from different sources of grains. Noodle products are particularly made from common wheat fine flour through a process of sheeting and cutting. Since most noodles are machine-made, the apparent manufacturing process may differ from one country to another (Fu 2008).

Indeed, there is no specific classification for Asian noodles as large gap exists between countries. The difference from one country to another has made it difficult to categorize the noodles accordingly. By taking into account the raw materials, noodles can be categorized accordingly to wheat noodles, buckwheat noodles, starch noodles, and rice noodles. The noodles are then further characterized through its processing methods into fresh, frozen and dried noodles in parallel to the research content.

2.1.1 Wheat Noodles

In general, noodle manufacturing makes up 40% of Chinese wheat production (Fu 2008). Wheat flour is the dominant ingredient for producing Asian noodles. The noodle is made by a relatively simple manufacturing process (Janto et al. 1998) Flour, and water are mixed evenly into well distributed ingredients to further hydrate the flour particles, and alkaline salts to form a crumbly dough. Other ingredients can even be food colouring, starch, liquid egg, preservatives and gums.

The dough is then compressed between rollers a few millimetres apart to form a sheet of dough. Since the noodle surface is rough prior to first pass, therefore two dough sheets are combined to improve the surface. The combined dough is generally rested to relax the gluten structure before subjected to three to five passes through the sheeting rollers. Sheeted doughs are slit carefully into multiple strands by using slotted cutting rolls to produce noodles of specific width and lengths (Ali et al. 1999)

Figure 2.1 Wheat Noodles

The sequence of dough mixing, sheet forming, compounding, sheeting, and cutting are consistent for all machine-made noodles. Noodle strands rolling through the cutting rolls can be further processed for the production of variety noodles (Fu 2008) The wheat noodles as in Figure 2.1 are ready for sale, or are further processed to prolong shelf life, to either modify eating attributes or to enable preparation by the consumer. Thus, the quality improvement of noodle is hugely important for wheat breeding programs in China (Hou & Kruk 1998). In fact, texture quality has been evaluated by governing different type of US hard white wheat varieties on different fresh and wet noodle styles in Taiwan, Thailand, and Malaysia (Janto et al. 1998).

2.1.2 Buckwheat Noodles

Noodles made from buckwheat flour or called as soba as in Figure 2.2 are found mainly in northeast China, Korea and Japan. Buckwheat belongs to the family of Polygonaceae, as a different breed of plant (Yu 2003). On the contrary to the normal cereal grains like barley, buckwheat is a sharp, three-sided seed with dark brown colour.

Figure 2.2 Buckwheat Noodle

The buckwheat flour is generally mixed with some wheat flour to benefit from its gluten in binding the flour together. As hand-made noodles are made from a blend of 2–3 parts of wheat flour to 7–8 parts of buckwheat flour, the machine made soba requires a 40–80% of wheat flour to eventually increase its binding power. It is essential not to supply excess heat to the rollers during milling as heat definitely affects the quality attributes of any food. The stone-ground is deemed to be the ideal method of milling buckwheat (Ma et al. 2013)

In Japan, buckwheat flour produced from the buckwheat kernel (No. 1 flour) contributes 25% of its total production. The respective 35%, 30% and 10% of the buckwheat flour are made up from the respective flour from the rest of the endosperm (No. 2), from the seed coat (No. 3), and from the part closest to the hull. As typically known as Soba in Japan, these brown or grey-coloured noodles are usually served cold in summer and warm in winter. Soba comes in the form of dried soba, boiled soba, and fresh soba which in 2000, makes up 8.5% of total Japan noodle production (Ma et al. 2013).

2.1.3 Starch Noodles

Different sources of starches like potato, yellow peas, and mung bean are widely used which have been long practiced in China. The origin of starch noodles as in

Figure 2.3 remains an unsolved historically recorded (Tan et al. 2009). Starch noodles are also called cellophane noodle due to their translucent appearance subjected to before or after cooking (Kasemsuwan et al. 1998). Thus, the type of starch itself hugely influences the production of starch noodle and the final starch noodle quality. A good quality starch noodles would have clear and fine strands, low cooking loss, high tensile strength, despite long cooking (Tan et al. 2009)

Starch noodles are distinctive from other variety of noodles including wheat noodle and pasta because it is prepared from gluten-free starch. Starch noodles are transparent, slippery, glossy, and in thin strips when uncooked which were made from purified starch from different sources of plant. The cooked noodle should be elastic, transparent, smooth, and non-sticky which has a bland taste with good mouthfeel. Traditionally, this typical transparent noodle was made during the winter season and consumed in soup or fried dishes.

Figure 2.3 Starch Noodle

The main traditional ingredient in starch noodle making has always been mung bean starch. Mung bean starch is the major raw material for starch noodle particularly in China and Thailand. Noodle made from whole mung bean starch is generally graded under specific quality. In Malaysia, mung bean starch is mostly imported from China and Thailand and thus expensive (RM6.0/kg). The utilization of mung bean starch in starch noodle production is eventually costly. Prior to short cooking, mung bean noodles describe a low loss of solids on prolonged cooking to produce a higher chewiness and higher elasticity texture. Mung bean starch has abundant amylose content and functions as chemically cross-linked starch to display restricted swelling and solubilization.

The use of other starches like corn starch, potato starch, pigeon pea starch, sweet potato starch, has been further investigated. Unfortunately, the noodles produced from non-mung bean starch are of lower quality compared to the mung bean noodle. These noodles were found to be softer and less transparent with higher percentage of cooking loss.

However, potato is an alternate substitute for mung bean in starch noodle rather than other starches. Plus, potato starch is deemed as cheaper at RM 1.60/kg than mung bean starch. In Malaysia, the only starch noodle produced in market is made up of 95% potato and 5% mung bean starches. Despite different physicochemical properties of potato starch from mung bean starch, starch from potatoes has been alternatively used to produce anticipated starch noodles. Potato starch is preferable over cereal starches for manufacturing starch noodles because of the elasticity of the noodles produced, its neutral taste, and much higher transparency (Fu 2008).

2.1.4 Rice Noodles

Rice noodles consist of many names, nationalities, and dishes. In fact, the names are phonetic translations so the spellings may vary slightly across brands. For example, similar language like Chinese does offer different names of hé fěn and guǒ tiáo due to its variety. However, they are easiest to identify simply by their four principle sizes: vermicelli, thin, medium and wide.

Indeed, fresh rice noodles are soft, flexible, and have a milky white colour. In fact, noodles made from rice flour are more delicate than those made with wheat flour since they do not have gluten to hold them together. Due to that, rice noodles (mi-fun) have been identified as the second principal form of rice product widely consumed in Asia after cooked rice grains (Bienvenido O. Juliano 1993). They may either be cooked in a broth as a soup or stir fried together with any kinds of meats, and vegetables. Before that, rice noodles need to be soaked in hot water (not boiled) before adding them to the meal. Boiling rice noodles merely turn them to be mushy and unfavourable.

Traditionally, they are made solely from long-grain rice with more than 22 % of amylose content (Bienvenido O. Juliano 1993), and water that come in folded sheets, which is essential in forming a gel network and supports the noodle structure (Li et al. 2016). A report has correlated that high amylose content of rice produced higher acceptance of rice noodles (Fari et al. 2011). Rice varieties with hard gel consistency and high amylose made up good rice noodles (Bienvenido O. Juliano 1993).

The nutritional fact of fresh rice noodles prior to packaging is found in Table 2.1. It can be learnt that fresh rice noodles prior to packaging relatively contain very low or negligible fat content. The rice noodles are then placed in multiple racks for the purpose of packaging. From the nutrition facts of sealed rice noodles found in the packaging as in Table 2.2, the fresh rice noodles available in the market have a layered coating of oil to keep the notoriously sticky noodles from physically sticking together. The coating oil can be corn oil, and palm oil subjected to the noodle manufacturers which may be removed by rinsing them with hot water prior to cooking (Asekun et al. 2007).

Table 2.1 The nutrition facts in a plain fresh rice noodle per 1 serving (28.3 g)

*Percent Daily Values are based on a 2,000 calorie diet. Your daily values may be higher or lower depending on your calorie needs.

Calories 53
Total Fat 1 g Saturated fat 1 g Polyunsaturated fat 0 g Monounsaturated fat 0 g
Cholesterol 0 mg

Sodium 1 mg			
Potassium 0 mg			
Total Carbohydrate 12 g			
Dietary fibre 0 g			
Protein 1.0 g			
Vitamin A	0%	Vitamin C	0%
Calcium	0%	Iron	0%

Source: (MyFitnessPal 2014)

Table 2.2 Nutrition facts of sealed rice noodles, in packaging

NUTRITIONAL INFORMATION Serving size: 100g	
Fat	1.00%
Protein	7.05%
Carbohydrate	32.75%
Energy	1.69%

Indeed, there are two fundamental strategies utilized for the production of rice noodles: expulsion, which is utilized to create vermicelli sorts; and sheeting of a layer, which is utilized to deliver sheets and level noodles. Rice vermicelli noodles are produced using high amylose rice which is wet-processed in the wake of soaking in water for a few hours. The processed rice is sifted, pounded, and shaped into balls. The balls are pre-cooked in bubbling water for around 20 min or steamed to empower surface gelatinization.

The halfway cooked balls are then plied to consistently circulate the gelatinized rice all through the dough mixture to go about as a binder. Moreover, the mixture is extruded via a die. The extruded noodles drop into the boiling water and float when sufficiently cooked, on the surface of the boiling water. The cooked noodles are instantly moved into a tank of cold water for cooling.

As the alternative processing procedure, the extruded noodles are arranged immediately in racks and subjected to steaming for 10– 15 min. Next, they are soaked in running water, before being dried in plate. In Japan, dry-processed rice flours have been utilized as a part of place of wet-processed rice flours. The dry flour is blended with water, warmed around 1 minute at 100 °C to permit halfway starch gelatinization, and afterward worked in a screw kneader before expulsion. Uniform and straight strands, white and translucent shading, and the absence of broken strands are attributes of high quality rice noodles.

After soaking in heated water, superior quality noodles hydrate with least surface stickiness and turbidity. Flat or sheeted fresh rice noodles are well sought after in southern China, Japan and many parts of Southeast Asia. A wet-processed rice batter is covered onto a rotating heated drum and the sheet is peeled off and passed on to a steaming passage whereby gelatinization takes place. The level of pre-gelatinization of rice flour assumes an imperative in giving acceptable noodle surface. However, some level of gelatinization is required as excessive gelatinization may only trigger noodle surface issues (Fu 2008).

2.2 RICE NOODLES TREATMENT METHODS

The noodles are further classified through its processing methods into fresh, frozen and dried noodles.

2.2.1 Pre-treatment

The pre-treatment process is introduced in the study by soaking oil-coated rice noodles in distilled water to represent the non-oil coated sample of rice noodle. The detailed process is explained further in the next chapter. However, noodles with the mentioned pre-treatment does not seem to be practised therefore soaking in other food products are reviewed.

Soaking treatments had a significant effect on the whiteness of dried mushroom slices *(Agaricus bisporus)* compared to other samples but the rehydration ratio was very low (Nour et al. 2011). In the meantime, soaking regardless time, prior to oven-drying at 50°C has enhanced the fat and moisture content, but reduced the nutrient content of the bitter yam flour (Egbuonu et al. 2014).

The main challenge in making non-fried instant noodles like rice noodle is to avoid the noodle strands from sticking, which usually causes non-uniform drying. On the contrary to pre-treatment, spraying oil on noodles during steaming which represents the original rice noodle in this present study merely slowed down the drying process due to the resistance towards moisture removal (Hou 2010). To make matter worst, the dried noodle may not be able to separate easily to eventually cause uneven rehydration and poor texture.

2.2.2 Fresh Noodles

With the production of up to 46% in China and 15% in Japan, fresh rice noodles still hold big shares in the food market. Therefore, plain fresh rice noodle are an important component of traditional Asian cuisines and noodle specialties may vary according to specific region. Plain noodles market is dominated by the private owned companies with the majority of market players are being local, small and medium-sized enterprises. However, in Japan alone, volume sales of fresh noodles are recently anticipated to decline by 6.1% between 2009 and 2014, while their retail value sales should drop by 10.2% during such period due to increasing hectic working trend (Cham & Suwannaporn 2010)

The simplest approach to classify fresh rice noodles is through its processing method either hand-made or machine-made noodles. Traditionally, fresh rice noodles are produced from long-grain rice with intermediate to high amylose content (>22% amylose). Due to their favourable distinguished taste, hand-made types are always available across Asia, which were prevalent before the automatic noodle machine began to take over in the 1950s. However, stretching noodles by hand is indeed claimed a culinary art rather than noodle making. Furthermore, the noodle machineries are best utilized for massive scale production (Thomas et al. 2014).

In general, the processing procedure of noodle includes mixing raw materials, dough sheeting, compounding, sheeting/rolling and slitting is consistent throughout the Asian continents. Extruded noodle strands out of slitting rolls are directly cut into specified lengths without subsequent processing prior to packaging. Due to quick discolouration, the noodles are often consumed within 24 hours after purchasing. Their shelf life can the least be adjourned up to 3 to 5 days if subjected under properly tight refrigeration (Sandhu et al. 2010)

2.2.3 Frozen Noodles

Despite dining out has generally been a common social event all across Asia, the economy recession has resorted people to restrict the frequency of meals eaten out. Thus, instant, chilled and frozen noodles have found complacent spot among consumers, as they are time and cost-effective alternatives than food eatery, particularly during lunch break. In fact, out of the total noodles consumption, frozen noodles stood at 2% in China and 10% in Japan respectively (Gary G. Hou 2010). Increasing popularity of ready-made meals due to less time for meal preparation has resorted consumers to look for a more convenient meal option, particularly when the number of families decreasing.

The frozen noodle is initially prepared as a fresh meal. To maintain the freshness, the cooked vermicelli is then mixed thoroughly with black soy sauce and rice bran oil to bring forth the ready-to-freeze meal. The moisture content of dried vermicelli should be adjusted to 50% prior to mixing with black soy sauce and vegetable oil at a ratio of 500:20:20 by weight. As there is strictly limited information on frozen rice noodle product, especially in the manner of ready-to-cook, frozen rice noodle product is made by performing cryogenic freezing process. The Vermicelli and gravy, either consists of potato starch with gelatine or modified cassava are separated and cryogenically frozen using liquid nitrogen, given the product should be able to withstand freeze-thaw process up to 5 cycles. The thaw process of both frozen vermicelli and gravy are provided by using microwave at 900 Watts for 2 minutes and 5 minutes, respectively (Surojanametakul & Varanyanond 2007).

Being known as a rather effective method of food preservation, freezing however, may cause some deterioration in frozen food quality during storage caused by several factors. Cooked starch gel always demonstrates positive changes in its quality among the frozen food products during freezing and thawing particularly in retrogradation, syneresis, and textural attributes. Indeed, the phase change in carbohydrate triggers the physical properties and stability of particular food substance. Consecutive freeze-thaw cycles deteriorate the phase separation which leads to the build-up of larger coarse ice crystals to make up the starch structure. Most of the time, the botanical resources largely determine the stability prior to freeze thaw cycles of starch gels. The frozen food product at multi freeze-thaw cycles should contain microorganism within the standard limitation. The total plate count of the products shall not be higher than 3.0 × 103 cfu/g, and other microflora such as E. Coli and Coli form should be less than 3 MPN/g with no pathogenic to be found (Surojanametakul & Varanyanond 2007).

In fact, frozen rice noodles were favourable ever since its introduction to the market as the taste preference of most consumers towards frozen rice noodles in parallel to the prepared instant noodles. Most of them found that frozen rice noodles as equally practical to store as instant noodles. In spite of seeking for eating out at a cheaper rate, customers might choose something with more sustenance than instant noodle cups. Simply, the frozen noodle product could usually last up to 3 months under the storage at -20°C. Therefore, the market for frozen food grows interest as well as the demand for ready to eat food variance grows. However, both chilled and frozen noodles have experienced slight production volume growth starting in 2009 since the soft launching of dried noodles which seem to be more pronounced (Liapis & Bruttini 2009).

2.2.4 Dried Noodles

The drying behaviour of noodle variety has been recently studied by many researchers. In according to critical water content to indicate noodle deterioration, dehydration process to produce semi-dried noodles was performed by employing high-temperature–short-time (HTST) at 105–135 °C and medium-temperature–long-time (MTLT) at 45–75 °C. The birefringent analysis was done by using differential scanning calorimeter (DSC) to show approximately 30% starch gelatinization in HTST semi-dried noodles. In the meanwhile, a more compact noodle surface, with uniform pores in the cross section could be observed through scanning electron microscopy (SEM) images showed due to enhanced protein–starch combination prior to HTST dehydration. Furthermore, HTST induced protein polymerizations in noodle samples, mainly due to –SH–S–S interchange, which resulted in significantly ($p < 0.05$) shortened cooking loss. Moreover, HTST noodles exhibit higher colour and microbial stability. More importantly, the shelf-life of dried samples at 120 °C was extended to 5 days compared to 1 day of the control sample (Li et al. 2016).

The optimal ratio of noodle from banana flour was investigated using sensory qualities by the substitution of wheat flour with the percentage of 10, 20, 30, 40, and 50 of banana flour in reference to the control (100% wheat flour). The noodle formula development resulted that the increment of banana flour proportion reduced the stickiness of the noodles and induced the appearance to become darker. The banana flour replaces 30% of the total wheat flour in the formula in order to make up the optimum ingredient of 20.45% banana flour, 47.72% wheat flour, 20.45% water, 6.82% egg powder, 2.04% salt, 1.36% propylene glycol, 1.02% sodium carbonate, and 0.14% polyphosphate. Dried noodles were nutritionally made up of 13.7% protein, 4.8% dietary fibre which includes 2.8% of resistant starch and 0.12% fat. The texture analysis determines the breaking length and tensile strength of cooked noodles to be at 67.2 mm and 16.4 g respectively. The consumers evaluated the overall preference of uncooked and cooked noodles to be merely moderate. Thus, the recommendation to substitute unripe banana flour to be a potential source of fibre prior to solely wheat flour in dried noodle products is valid. The study suggests the integration of 30% unripe banana flour in the present noodle formula to enhance their resistant starch content and total dietary fibre significantly (Ritthiruangdej et al. 2011a)

The flat pasta was subjected to low temperature (LT) drying at 50 °C for 20 hours, high temperature (HT) drying at 70°C for 11 hours and at very high temperature (VHT) drying at 85°C for 4 hours. Pasta surfaces were observed by scanning electron microscope (SEM). Both low soaking temperature (40-55 °C) and high soaking temperature (75-90 °C) did not exhibit significant differences in water absorption rate among LT-, HT- and VHT-dried pasta. However, LT-dried pasta had the largest water absorption rate near the starch gelatinization temperature (60-65 °C). However, when dried pastas were soaked below the gelatinization temperature, phase differences of LT and HT-dried pasta were larger than the differences of VHT-dried pasta. Thus the study suggested that phase difference of pasta is independent on drying temperature alone, but also on the gelatinization distribution and moisture content (Zhang et al. 2011).

The fresh Udon of different moisture contents was subjected to constant drying conditions at different temperatures of 20, 30, and 40 °C. The effective moisture diffusivity obtained was ranging from 2.1×10^{-7} to 3.7×10^{-7} cm^2 s^{-1}. Despite the effect of moisture content was quite negligible, the effect of temperature on effective moisture diffusivity has been satisfactorily modelled by the Arrhenius relationship (Inazu & Iwasaki 2000). The incorporation of different proportions of salt on the drying characteristics of fresh salted noodles was then examined. The drying rate for fresh salted noodles decreased as the amount of salt increased, thus adding salt generally influenced the drying kinetics of a product. However, mostly the studies were on the effect of multiple treatment on starch noodles and the studies on transparency phenomenon of rice noodles were very limited in literature (Chen et al. 2014).

In another work, pasta was subjected to a hot air drying at 55 °C to achieve 13.0 % of final moisture content. The noodles produced by wheat straw supplements, maize flour, and extruded maize flour recorded the highest total sensory score. Supplementation with wheat straw, maize, defatted soy flours, and extruded maize could be adopted to render pasta of no eggs, enriched with dietary fibre with a lower glycaemic index and a reduced cholesterol content (Ugarčić-Hardi et al. 2007). In the other study to establish a novel technique of producing instant noodles, the drying kinetics of noodles was investigated due to simultaneous drying and processing by using superheated steam. The constant rate drying period suggested by measurement of internal noodle temperature was much longer and well defined for all processing conditions than from the drying curves. It can be resolved that isotherm equations for equilibrium moisture content in hot air drying may be used to model isobars in superheated steam (Pronyk et al. 2010).

2.2.4.1. Drying Process

Conventional drying (hot air) offers dehydrated products of an extended life of a year by utilizing a parallel technology and equipment. However the product quality prior to conventional drying is hugely declined from the fresh state of product (Ratti 2001). Product subjected to drying can be heated either by volumetric heating or surface heating and it can even be fixed position or positioned in specific motion. In order to design a hot air drying process, a detailed assessment of all the factors influencing its quality is required (Lewicki 2006).

In order to increase the drying rate as well as enhancing the quality of dried product, several drying factors were put into consideration. Four main parameters which affected drying process were the thickness of solid being dried, air temperature, air humidity and air velocity. Thus, there was a urgent need to develop a faster drying techniques and procedures of high energy efficiency (Mongpraneet et al. 2002).

In general, the effect of drying temperature has become the most studied parameter in most drying processes. It came to the logic that by increasing the drying temperature, the drying time shortened as the drying rate was eventually increased. It is most preferable when the drying process accounted the shortest drying duration but unfortunately high drying temperature should lead to harsh quality degradation of the dried product.

Basically, drying air temperature is an important parameter for the efficiency of the drying process. The rate of moisture removal increases as the air temperature increases with the other drying conditions remain resulting substantial decrement in drying time (Doymaz et al. 2006). Prior to similar publication, the increment of drying temperature increases a* (redness) values and decreases L* (brightness) and b* (yellowness) values.

2.2.4.2. Theory and Principles of Drying

Drying or dehydration is a simultaneous mass and heat transfer mechanism of moisture removal to produce dry solid. The simultaneous occurring transfer processes are:

- Transfer of heat from surrounding environment to remove the surface moisture.
- Migration of internal moisture to the external surface of solid and evaporates.

The drying kinetics can be further analyzed from the drying curve.

The moisture content is usually calculated either based on wet basis (% wb) or dry basis (% db) as follows:

$$\text{Moisture content (\% wb)}, \; M_{wb} = \frac{W}{W+S} \times 100 \quad (1)$$

$$\text{Moisture content (\% db)}, \; M_{db} = \frac{W}{S} \times 100 \quad (2)$$

where W is weight of water within product (kg) and S is the weight of dry solid (kg).

Figure 2.4 displays the moisture content decrement of a solid during any air drying process. Drying process is accounted into four main phases (Geankoplis, 1993):

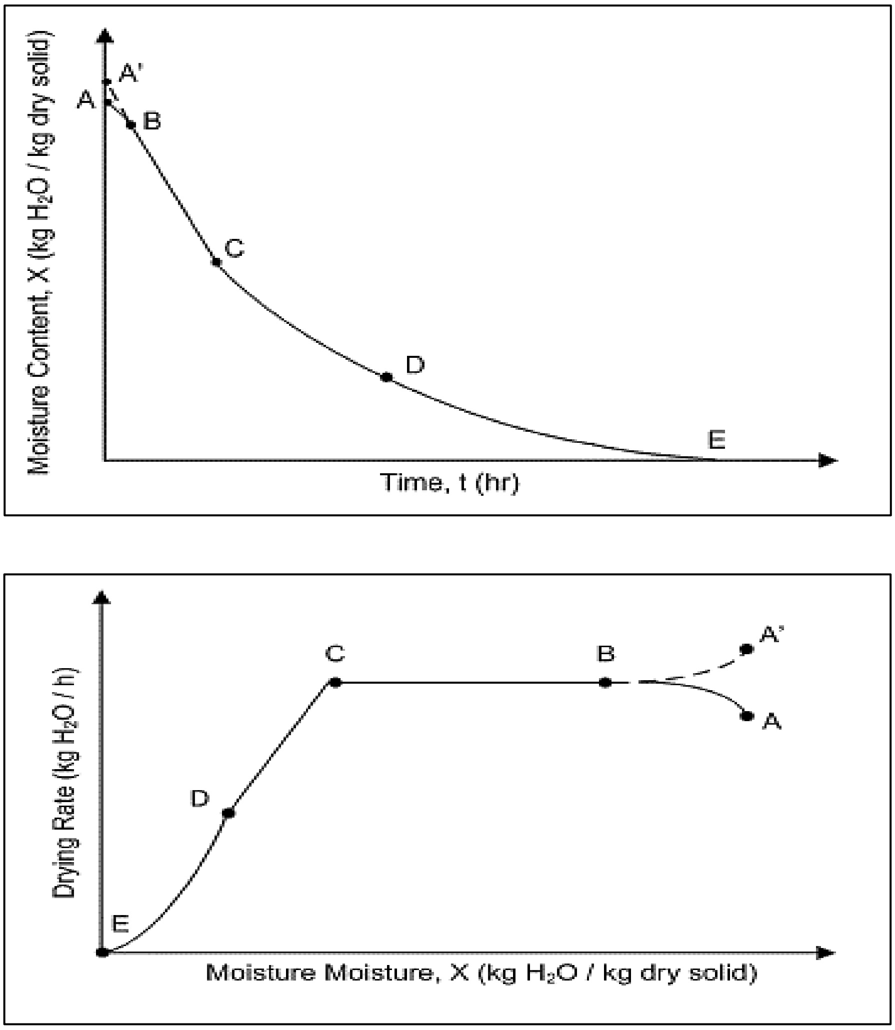


Figure 2.4 Typical drying curves of moisture content vs. time and drying rate vs. moisture content (Geankoplis, 1993).

A – B : At time = 0, point A indicates the initial free moisture content. The temperature of the product is generally colder than its current temperature. The product solid heats up so that the evaporation rate increases. At point B, the surface temperature moves to its equilibrium. The drying rate is established at point A' subjected if the product is sufficiently hot.

B – C : A straight horizontal line describes the consistent dehydration rate throughout the period. It is known as a constant – rate period. The removed water at this period is called as unbound water. This water moves freely at solid surface to create a constant film of water to easily escape on the drying surface. Such consistency proceeds shall the water mitigation rate to the surface equalizes its evaporation rate.

C – D : This first falling–rate period starts at point C. There is insufficient unbound water to maintain the surface wetness. Dry shrinkage starts to be visible on the texture whereby the surface reaches its equilibrium at point D.

D – E : This section is the second falling–rate period. The drying rate declines more rapidly throughout this period. Indeed, the drying rate is merely inhibited by the water diffusion inward the product solid through the drying front. The drying process cuts down gradually before reaching its final equilibrium at point E.

2.2.4.3. Mathematical modelling for drying

Drying is a very complicated process whereby the fundamental chemistry and physics of drying is highly seek after in order to take mass and heat transfer mechanism into account within the drying material (Mujumdar 1997).

Apart from regarded as a highly complex process unit, a dryer is merely an equipment which is efficient in removing moisture. Thus, effective theoretical models are required in process design, optimization, control, and energy integration. As of now, there is no theoretical models which may describe the overall equations practically (Marinos-Kouris & Maroulis 1995).

In fact, Fick’s second law of diffusion has been generally applied for most theoretical drying models. A wide range of food varieties have been described by Fick’s second law with Arrhenius type temperature dependent diffusivity. (Moss & Otten, 1989) recommended that many assumptions shall be made so that this law is valid to describe the falling rate period of foods.

Indeed, employing two different types of drying methods give two different value of effective diffusivity. Table 2.3 summed up the values of effective diffusivity of different dried noodle products. According to the table, the effective diffusivity value of the incubator and desiccator drying of Japanese Udon is higher to bench-top drying of Korean-type Rehmannia noodle at the similar range of temperature. Therefore, it dictates that the value of effective diffusivity totally relies on the drying process and the nature of the materials to be dried and not necessarily on mere temperature.

Table 2.3 Effective diffusivity of different noodles

Material	**Drying method**	**Temperature (˚C)**	**Effective diffusivity, D_{eff} (m^2/s)**	**Reference**
Japanese Udon	Incubator and Desiccator	20, 30, 40	2.1×10^{-7} to 3.7×10^{-7}	Inazu et al., 2000
Rice Noodle	Hot air drying	55,70, 85	1.96×10^{-11} to 3.91×10^{-11}	Kongkiattisak et al., 2012
Non-fried Instant Noodle	Convective Air Drying	80 to 120	4.41×10^{-8} to 1.75×10^{-7}	Zhou et al., 2015
Korean-type Rehmannia Noodle	Bench-top Drying	30,40,60,80, 90	3.05×10^{-11} to 1.09×10^{-10} (initial stage) 1.44×10^{-12} to 5.51×10^{-12} (latter stage)	Jhong-Whan, 2009

Semi-theoretical models are principally classified due to their derivation as Fick's second law of diffusion and Newton's law of cooling. In details, Fick's second law consists of models derived solely from Fick's second law of diffusion. It can be further classified in sub group which is single exponential and two terms exponential model and its modified forms as well as three term exponential model. Meanwhile, the Newton's law of cooling is defined in sub group such as Lewis model, Page model and other modified terms. This is the semi theoretical models that are derived with Newton's law of cooling.

By simplifying the general expression of Fick's second law, semi-theoretical models are derived but only valid within the moisture content range, air flow velocity, relative humidity, and temperature (Özdemir & Devres 1999). Indeed, such model derivation acquired fewer time than the theoretical thin layer models in which the assumptions of a certain food's geometry are not required (Parry 1985). Table 2.4 listed down the commonly used thin layer models for the drying purpose of food commodities.

Empirical models correlate a linear relationship between average moisture content and dehydration time. However (Irudayaraj et al. 1992; Keey 1972) pointed out that even though empirical models are able to define the drying curve for the drying condition by overlooking the fundamentals of the process itself, this has caused false substance of the key process throughout the process. Therefore, Thompson model is the only available empirical models to serve such purposes.

Table 2.4 Thin layer models commonly used in drying of agricultural products.

Model Name	Equation	Reference(s)
Lewis	$MR=\exp(-kt)$	Bruce (1985)
Page	$MR=\exp(-kt^n)$	Page (1949) cited by Bruce (1985)
Modified Page	$MR=\exp(-kt)^n$	Overhults et al. (1973)
Two-term	$MR=a\exp(-k_1t)+b\exp(-k_2t)$	Henderson (1974)
Handerson and Pabis	$MR=a\exp(-kt)$	Henderson and Pabis (1961)
Logarithmic	$MR=a\exp(-kt)+b$	Yaldỳz and Ertekỳn (2001)
Midilli et al.	$MR=a\exp(-kt^n)+bt$	Midilli and Kucuk (2003)
Thompson	$t=a\ln(MR)+b\ln(MR)^2$	Thompson, Peart, and Foster (1968)
Wang & Singh	$MR=1+at+bt^2$	Wang and Singh (1978)

**t is drying time while a, b, k, and n are defined as drying constants.

The statistical methods of regression and correlation analysis are often required to derive the mathematical modelling of the drying of food products. Linear and non- linear analyses are required to find the relationship between the variables. All the drying equations demand the moisture ratio (*MR*) deviation across time (*t*). Thus, *MR* data is plotted against *t*, and the regression analysis was performed with selected models to verify the constant values to eventually decide the appropriate models.

The validation of the models in the literature is basically executed according to the relation correlation coefficient (*r*), root mean square error (*RMSE*) and reduced chi-square (χ^2) test . However, correlation coefficient (*r*) has always been the substantial parameter in choosing the fitting equation to best describe the particular drying process.

2.2.5 Hot Air Drying (HAD)

Higher drying temperature of oven drying better preserves the mineral content of rosemary leaves (Arslan & Musa Özcan 2008; Arslan et al. 2010), the amount of bioactive compounds in betel leaves alone (Pin et al. 2009), and total flavanol content of the olive *(Olea europaea L.)* oil (48-62 mg catechin equivalents [CTE] 100 g-1 DM) except for 80 °C (Uribe et al. 2014). With the constant values of springiness and cohesiveness, higher temperature also increases the total colour change (DE), hardness and chewiness of chempedak *(Artocarpus integer)* (Chong et al. 2008) and the darkening of rosemary (Arslan & Musa Özcan 2008; Arslan et al. 2010).

In fact, drying button mushroom under air temperature of 50 °C was better as it resulted in dried products having better rehydration characteristics and lighter colour. Soaking in 0.5% citric acid and 0.5% ascorbic acid had a significant effect on the whiteness and total colour change of dried mushroom slices despite a very low rehydration ratio (Nour et al. 2011). In the meantime, under similar air velocity of 0.9 m/s, onion slices took shortest drying duration at air temperature of 70°C and the longest at an air temperature of 50°C. As thermo-sensitive compound, the loss of vitamin C was found to be the least at the temperature of 50°C (Olalusi 2014).

In comparison among drying media, the greenness and total colour of the kaffir lime leaves dried with hot air at 60 °C had a greater change than dried with CO_2 and N_2 (Poomsa-ad et al. 2011). The decrement in slice thickness and increment in drying temperature of kiwi slices increased the effective moisture diffusivity (D_{eff}). The D_{eff} value of the kiwi slices was recorded highest at 1.5681×10^{-8} m^2 /min at the slice thickness of 0.6 cm. Kiwi slices subjected to 60°C recorded the highest drying rate and retained the highest value of Total Phenolic Content (TPC) in the sample. As expected, subjecting kiwi slices at high temperature merely diminished the vitamin C of kiwi due to high thermal degradation (Chin et al. 2015).

Prior to sample thickness and air temperature, the drying time is ranging from 50–140 min to reach the commercial moisture content of pestil (0:12 kg H2O=kg DS) in hot air drying (Maskan et al. 2002). The drying behaviour of the garlic *(Allium sativum L.)* slices was investigated in a thin layer hot air drying at slice thicknesses of 2, 3 and 4 mm and air temperatures of 50, 60 and 70°C. The variation of effective diffusivity coefficient was depended on temperature by Arrhenius relationship (Rasouli et al. 2011). In the meantime, the drying of okra falls in the falling rate period. The sample subjected to 40°C was found to be superior in taste, texture and colour in contrast to the samples dried at 60 °C and 90°C. The drying kinetics were somehow fitted to particular drying models (Wankhade et al. 2013).

Furthermore, the moisture contents of the external layers of the long-grain (*var. L201*) and short-grain (*var. Akitakomachi*) rough rice kernels decreased during the drying periods and increased during the tempering periods with the consistent decrement of the moisture content of the internal layers of the kernels through the whole intermittent drying (Dong et al. 2009). Furthermore, the reduction in energy consumption by intermittent drying of the cylindrically shaped kaolin is prior to variable air temperature and greater by variable air humidity on the contrary to drying at static conditions (Kowalski & Pawłowski 2011).

Meanwhile, the air temperature (60, 80 and 100 °C) and tempering time (0, 15 and 30 min) were examined to study the drying kinetics and quality of yerba maté branches (colour parameters *L* and *b*, and the sugar and caffeine contents). However, the influence of tempering time was significant at 60 °C with no differences between 15 and 30 min tempering times (Ramallo et al. 2010).

2.2.6 Heat Pump Drying (HPD)

Heat pump dryer regains energy through flue gas in order to control the humidity and drying air temperature. In principal, heat pump system is made up of a compressor, an evaporator, an expansion valve, and condenser (Ong & Law 2011). The specifically designed heat pump dryer is recommended in industries due to a wide range of air flow rate. It provides a good platform to study the drying kinetics of various products and the energy consumption of the process (Fatouh et al. 2006).

Heat pump dehumidifies the external air prior to be insufflated by the evaporator in order to be heated up instantly as soon as it passes through the compressor from where it dries up. After that, hot air flows out in accordance to the thermodynamic conditions to perform the drying process of a product. Heat pump has proven to be a reliable drying technology to preserve the product’s quality particularly food and agriculture products. This is due to its ability to control the moisture content of the product at a gentler drying condition. In fact, by developing an improved heat pump dryer will eventually assist to increase the product quality as well as reducing the operation cost of the industry (Goh et al. 2011).

In food applications, heat pump drying provides better preserved product quality and superior energy efficiency. Furthermore, heat pump is a green technology that fumes and gases are not discharged to the atmosphere (Perera & Rahman 1997). The higher drying temperature in hawthorn cakes caused a faster drying process. The experimental results and the economic analysis indicated that the HPD was feasibly used to dry hawthorn cakes (Wang et al. 2011). The moisture content of agricultural products using HPD reduced to below 10% to prepare the chilli powder which deemed to be sufficient as an agricultural product dryer (Marnoto et al. 2012).

Heat pump drying is also good at nutrient retention of cocoa polyphenols, which ranged from 44% to 73% in contrast to freeze drying (Hii et al. 2012) and ascorbic acid content and chlorophyll content of green sweet pepper (Pal et al. 2008). In fact, dried cocoa bean hardness was reasonably consistent to the commercial product and increased with the declining moisture content. Furthermore, green sweet pepper recorded higher sensory scores and rehydration ratios. The declining quality trend with increase in drying air temperature from 30 to 45°C has suggested performing heat pump drying of green sweet pepper at 35 °C.

Furthermore, the moisture extraction rate (MER) in tomato quarters was found to be the highest in heat pump drying at 0.237 kgw/h and the lowest to be at 0.125 kgw/h in natural drying. Heat pump system provides enormous edges for tomatoes in producing higher drying speed apart from less intercedence on environmental restrictions, and less interfered by weather and surrounding factors of dust, insects, and rain (Karabacak & Atalay 2010). The small size herbs like parsley, spearmint, and Jew's mallow without stem consume short drying time and low total specific energy. Indeed, the productivity of a dryer is highly regarded in terms of drying air temperature, drying air velocity, and surface load (Fatouh et al. 2006).

Insufficient incorporation of operating parameters in heat pump dryers usually results in subsequent difficulties such as low dehumidification efficiency, too high/low discharge/suction pressures or even mechanical disturbance to the compressor. This is to ensure safe operating conditions to ease the application of heat pump drying in the industry (Minea 2010). However, the drying time of fresh apple, pear, ciku, papaya and mango dried by using convective vacuum microwave (C/VM) was found to be 50% shorter than different drying conditions including heat pump drying (Law et al. 2010).

This has eventually triggered the improvement to the conventional heat pump dryer. The *Ganoderma tsugae* which was due to intermittent heat pump drying has shorten the effective drying time to the conventional drying but preserved lower content of water-soluble polysaccharides in the intermittency decrement from 0.67 to 0.2. In fact, heat pump drying produced better chroma value and total colour change (*ΔE*) in comparison to vacuum-dried and oven-dried products (Chin & Law 2010). The model showed tempering of the product and increased surface moisture content when the air temperature was switched from the 'on' period to the 'off' period. The time-evolution of the product surface temperature and moisture and the drying front had been investigated for both constant and intermittent drying schemes (Chou et al. 2000).

Moreover, the drying kinetics of heat pump drying was performed in salak fruit slices under two different modes which were step-up air temperature and periodic heat air flow supply to not only increase the drying kinetics but also produce a stable dried product. The effects of air velocity and relative humidity were significant as the moisture content was high, and the effect of air temperature was predominant when the moisture content fell short (Ong & Law 2011). Employing stepwise-varying air temperature to the banana slices with the initial temperature and cycle time had reduced the drying time to hit the anticipated moisture content with enhanced colour retention (Chua et al. 2001).

In the drying process of Chinese cabbage seeds, percent energy saving over continuous drying was 48.1%. So there was an obvious advantage of intermittent drying over continuous drying in regards of energy efficiency (Yang et al. 2013). However, chopped alfalfa was dried in a cabinet dryer in batches and also by emulating continuous bed drying using two heat pumps operating in parallel. As a results, continuous bed drying is a potential better option than batch drying due to high air humidity ratios at the evaporator front whereby specific moisture extraction rate and constant moisture extraction rate can be well maintained (Adapa et al. 2002b).

Several advancements on HPD has been invented and executed. For example, the drying time of chilli subjected to vacuum heat pump dryer decreased with an increase of drying temperature or a decrease of drying pressure. Colour change and shrinkage percentage increased and the rehydration ratio notably decreased with an increase in drying pressure (Artnaseaw et al. 2010). Furthermore, the green peas were subjected to multi-stage heat pump fluidized bed atmospheric freeze drying (HP FB AFD) and microwave vacuum drying (MVD). It satisfied high product quality and increased the final drying rates (Zielinska et al. 2013).

The heat pump assisted recuperative air dehumidifier consisted of an air-to-air vapour compression heat pump, coupled to the air ducting. The present analysis was innovative through the introduction of an air-to-air plate recuperator, to trigger further dehumidification, at the higher compressor energy consumption (Pereira et al. 2004). The reduced browning, faster rehydration, and enhanced vitamin C retention in the final products highlighted the bright potential of the modified atmosphere heat pump drier in the food industry (Chen 2008).

2.2.7 Freeze Drying (FD)

The deterioration and microbiological reactions are mostly halted due to the absence of liquid water and low temperature in freeze drying to give a product of good quality (Ratti 2001). By studying the thermochemical and thermomechanical properties of water-soluble, amorphous materials formed the basis of effective formulation design to achieve optimum results with minimal experimentation (Franks 1998). The study on freeze drying primarily suggested the modification of pre-freezing, primary drying, secondary drying, addition of a solute and usage of mixed solvents to elevate the kinetics transfer without neglecting the dried product quality (Elia & Barresi 1998).

The studies of freeze drying were conducted in meat, apple slices coating, rice kernels, sweet potato cubes, and agricultural products. Under different thicknesses, speed of freezing, time of drying phases and pressure the Broiler chicken breast meat was subjected to physical and sensory analyses. Thus, the study suggested freeze drying as an efficient method to produce similar looks and tastes to the fresh poultry meat under appropriate process parameters prior to the lowest sample thickness (Babić et al. 2009). The bulk density of freeze-dried rice kernels and agricultural products like potato, mushroom and strawberry were increased with the applied pressure during freeze-drying, while porosity decreased. However, the bulk density and porosity of freeze-dried rice kernels behaved adversely with the increment of boiling time. (Oikonomopoulou et al. 2011).

Freeze drying of plain and added blueberries of white skim yoghurt was performed for the consumption in space. As a result, its viscoelastic properties were reserved whereby its unprecedented strength could be retrieved by adjusting the moisture content. Freeze drying reduced the lactic acid bacteria survival in a 2–3 log population. The levels of mortality were reduced prior to the adding sucrose and blueberries in the ingredients (Venir et al. 2007). Meanwhile, the increment of the sugar solution concentration significantly decreased the moisture content of the apple slices to affect its water activity, texture and sugar gain (Rahimi et al. 2013).

Sweet potato cubes were subjected to freeze drying, and freeze drying with far-infrared radiation. The drying kinetics suggested the latter method to reduce the drying time of sweet potato (Lin et al. 2005). The effects of product size, air velocity, bed temperature and freezing temperature on the freeze drying process were investigated in the shrimps subjected to freeze-drying under vacuum and at atmospheric pressure (Donsì et al. 2001). Comparison of spray granulation (SG), spray drying (SD), and FD processes confirmed that combination of matrices, drying temperature, microcapsule morphology, and processing time were among the most critical factors governing the stability of microencapsulated fish oil (Anwar & Kunz 2011).

In pharmaceutical production whereby freeze drying was very common, the freezing step was truly essential as it fixed the final product morphology. Bovine serum albumin (BSA) based formulation was subjected to stabilize pharmaceutical proteins during their freeze-drying process (Hottot et al. 2007). Moreover, two amorphous solutes which were moxalactam di-sodium and povidone and a crystalline solute known as mannitol were subjected to a laboratory freeze dryer. The study found that the moisture content descended rapidly for the initial hours of main drying before approaching a plateau level of residual water which exceeded the equilibrium moisture content (Pikal et al. 1990).

In the meantime, freeze-drying drying characteristics and nanocapsules (NC) properties were optimized through thermal treatment by the effect of annealing to improve the long-term stability (Abdelwahed et al. 2006). Microcapsules were prepared by employing freeze drying at two zein: flax oil ratios by using zein as the coating material. This has resulted in agglomerated small spheres to easily be available on market as functional food ingredients (Quispe-Condori et al. 2011). The application of freeze drying as well as the protective matrices was used to improve the microbial cell viability prior to the preservation of micro-organisms (Morgan et al. 2006). By taking into account the optimal cell concentration, optimal sucrose concentration and carbon starvation, the survival of *Pseudomonas chlororaphis,* an antifungal bacterium prior to freeze drying was found to be 26.6% (Palmfeldt et al. 2003).

Apart from solely freeze drying, more advance methods were introduced to further improve its performance. The instant vegetable soup was subjected to microwave freeze drying (MFD) by employing response surface methodology (RSM). The addition of NaCl content and sucrose content had successfully increased the drying rate and sensory quality, and shortened the drying time while adding sodium glutamate content was insignificant (Wang et al. 2010). Furthermore, microwave freeze drying (MFD) was recently introduced whereby the MFD drying rate of potato puree was significantly higher after adding salt and sugar (Wang et al. 2011) and the drying time of sea cucumber was reduced by about half (Duan et al. 2010).

The drying rate of several fruit and vegetable subjected to freeze-drying coupled with an evaporative freezing and a conventional freezing step, using on-line monitoring was also analysed (Ghio et al. 2000). High-quality crispy fruit pieces was produced by sequential infrared and freeze-drying (SIRFD) as a new processing method at reduced cost due to more desirable colour and more shrinkage (Shih et al. 2008). In the meantime, garlics were subjected to freeze-drying under atmospheric pressure in a fluidized bed of adsorbent fine particles. The garlics dried at -5 °C significantly had lower open pore porosity to the samples dried at -15 and -25 °C (Sablani et al. 2007).

2.3 QUALITY ANALYSIS OF DRIED PRODUCTS

It is learnt that rice with hard gel consistency, low gelatinization temperature, and high amylose were appropriate for preparing best plain noodles. Good quality of Chinese fresh noodle is described by its superior eating quality including aromatic taste, smooth, elastic, and cohesive with medium firmness, as well as bright cream colour, and flat-speckles surface. In addition to that, eating quality and texture together with colour are essential in determining the quality of fresh Chinese noodle. In the meantime, the quality changes of noodles such as sensory, physical, chemical, microbiological, and textural characteristics in particular to drying process were usually investigated (Ugarčić-Hardi et al. 2007).

2.3.1 Texture Analysis

A good drying process should preserve the noodle quality. Improper drying could cause cracking, over-elongation, splitting, and warping to the noodle strands. These are the conditions that are not desired in any proper handling and packaging. Despite fast drying is desirable, a very huge moisture gradient between the external layer and core of the product is usually created. As the surface starts to shrink while moisture escapes to the atmosphere, the noodle surface will contract to each other up to the wet core. This tenses up the noodle surface to eventually put the core at compression. This has caused noodle to calm these stretches by permanently deforming in a poor manner. In order to reduce further noodle structural disturbance, a proper multi-staging drying process should be employed. Therefore, three step drying which is pre-drying, drying, and cooling, is always a good exercise (Fu 2008).

The noodle texture characteristics are more complicated to understand. The textural preference is however region specific. A distinct difference in noodle bite can be learnt among these noodles. The Japanese type noodle is found to softer, while the other varieties are firmer. The noodles hardness which require high protein flour, are including Malaysian hokkien mee, the Chinese raw, wet and instant fried, Thailand bamee noodles and chuka-men (Janto et al. 1998). The Korean instant fried noodles are meanwhile firm in bite that required medium protein flour with substantial starch. Both strain at break point (SB) and maximum load (ML) increased to the increment of starch intake level and moisture content (Yu 2003).

In the meanwhile, for the noodles prepared from dry-milled flours with a lower retrogradation rate, the texture profile analysis (TPA) and tensile test is required. The flours may be improved by hydrating the flour prior to processing. In industrial scale, poor fermentation leads to bad texture with distinctive loss of chewiness, whereby over fermentation leads to off-flavour in the noodles (Gary G. Hou 2010). On similar note, the chewiness, springiness, hardness, and adhesiveness of laksa noodles made from small particle flour were significantly higher than the noodles made from large particle flour. In addition, the enhanced gelatinized starch developed better texture of laksa noodle. Thus, the smaller size of the rice particle flour simply produced better laksa noodle (Nura et al. 2011).

Since the tensile strength in seaweed noodles is low, the seaweed thus could not be deemed as a reliable ingredient to fortify network structures of noodle. Indeed, the higher protein content which is naturally due in seaweed resulting in the higher tensile strength (Dewi 2011). On another note, the tensile strength of banana noodles decreased to the increment of banana flour. Adding up banana flour, as a non-gluten flour, in the production of dried noodles interrupted the gluten strength of the flour to eventually weaken the overall structure of the noodles (Ritthiruangdej et al. 2011b).

However, there was no significant differences observed on the springiness, hardness, and adhesiveness in all medium and high temperature dehydrated semi-dried noodle samples, except chewiness. These observations confirmed that temperature did not have significant effect on the texture attributes of the semi-dried noodle products (Li et al. 2016). In addition, velocity was not significant on the noodle’s breaking strength averaged 1500 to 1600 g/mm^2 at the temperatures of 130, 140, and 150 °C. Nevertheless, superheated steam subjected to increasing drying temperatures turned down the stability of the dried noodles, which is due to a decrease in total breaking stress (Pronyk et al. 2010).

The common buckwheat noodle possessed greater tensility whereby more force was needed to break the noodle strands than tartary buckwheat. The effect of cultivars was found to be significant (p<0.05 to the adhesiveness). In details, *'Xinong 9909'* noodle had the greatest adhesiveness, followed by *'Xinong 9940',* which suggested that genetics had a distinct effect on the quality of buckwheat noodle (Ma et al. 2013).

The apparent texture of instant noodles is smooth, firm, and rubbery. Instrumental texture measurement of any noodle is such a reliable and convenient option to the sensory analysis. Compression test such as simple compression and texture profile analysis (TPA) and tensile tests is the common texture analysis test. In singular test, TPA is able to release a list of textural properties namely cohesiveness, gumminess, hardness or firmness, and chewiness. Indeed, the noodle texture is dependent on water absorption rate, flour quality, dehydration procedures, and ingredients used like salt or alkaline reagents as well as processing parameters like sheeting, steaming (Gulia et al. 2014).

Moreover, rice noodle drying in the temperature range of 25 to 60 °C is not significant on the textural quality of the cooked product. The declining moisture content on noodle surface during aging for a vast period has caused the decline in product elasticity. All the processing variables like solid content, aging time, and drying temperature are not significant on the textural properties of the cooked noodles (Tan et al. 2009).

On the contrary, texture of cooked noodles prepared by Bario and Basmati rice was analyzed in terms of tensile strength and elasticity. Noodles made from Bario rice had better tensile strength in contrast to Basmati rice. It is found that less force was sufficient to tear noodles derived from both rice types only after 3 days of storage at room temperature. Higher content of amylose gave the higher tensile strength. Noodle made of Bario rice has better value of elasticity modulus in comparison to Basmati rice. As a whole, elasticity modulus of rice noodle produced from two rice varieties increased substantially subjected to storage in correlating it to the high quality type (Thomas et al. 2014).

The texture of cooked product has been one of the most essential criteria that determine consumer recognition of any particular product. The texture of a cooked noodle was described as any present of resistance towards chewing and the mouth feel of its surface. Rice noodles with high amylose content demonstrated lower adhesiveness which implied less surface stickiness on cooked noodles. Such smooth and lean texture has constantly been an indicator of a good quality of rice noodle. Thus, *YR24088 Acp9* and *Chenmaai* rice cultivars had decent firmness, less adhesive, springier, and more consistent than the others (Han et al. 2011).

In the meantime, the substitution of wheat flour with unripe banana flour was studied in regards of textural qualities and physicochemical of dehydrated noodles. The study has identified unripe banana flour as a potential alternative for the conventional wheat flour in dried noodle products (Ritthiruangdej et al. 2011a).

The textural analysis of noodles made from potato and rice starches and their blends were conducted. From the texture profile analysis, the proposed starch gel was found to have better cohesiveness, chewiness, and hardness by comparing to rice starch gel. Incorporating rice and potato starch in the 1:1 ratio produced the good quality noodles in particular of their lower cooking time, transparency, slipperiness and higher cooked weight (Sandhu et al. 2010).

2.3.2 Colour Analysis

As one of the important parameter for the consumer preference, colour was a useful tool to evaluate visual quality for the market penetration of noodles (Asenstorfer et al. 2010). Colour was an obvious quality parameter. Fresh noodles were presumed to preserve the white translucent colour after drying process. Noodles of high quality were distinguished by the presence of long-consistent strands of translucent white (Fu 2008). In the study, $L*$ value of rice noodles decreased in fresh noodles prepared from both Bario and Basmati rice samples. In fact, the noodles got darker which was known as browning reaction with an increasing storage days under inconsistent room temperature. Browning occurred due to the polyphenol oxidase found in the flour of noodles. Higher protein content induced the darkening in noodles prior to storage. That was due to the oxidation reaction between protein and phenolic (Thomas et al. 2014).

In subsequent, the increasing amount of unripe banana flour promoted the darker appearance of raw sheet and cooked noodles supplemented with banana flour due to the Maillard reaction between proteins and reducing sugars (Mohamed et al. 2010). The redness value rose in significant to banana content as the yellowness decreased. The samples with increasing banana flour were darker due to the presence of excess sugar (Ritthiruangdej et al. 2011a). All types of noodles were valid with great brightness whereby the colour can either be yellow cream or white subjected to the alkali salts used. Indeed, minimal darkening was necessary for at least within 48 hours. Therefore, by dehydrating the noodles to produce dried noodles or instant noodles, the colour stability could be mostly preserved (Hou & Kruk 1998).

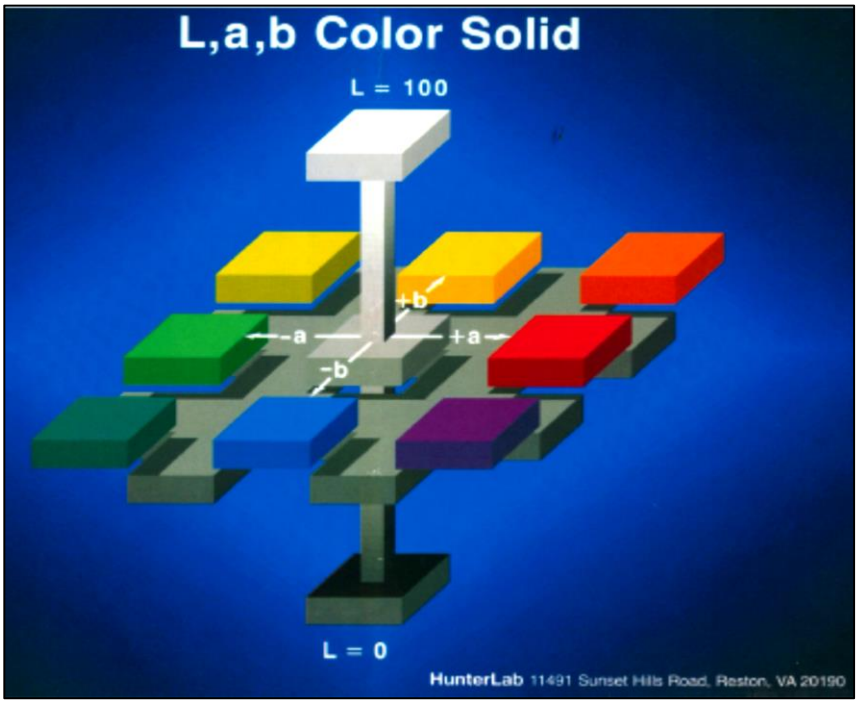


Figure 2.5 The HunterLab colour space (Shyam N. Jha 2010)

Next, the pasta colour of wheat straw (WS), defatted soy flour (S), extruded maize, lecithin (L) maize, and maize/soy flour (SM) blends was compared to the fresh pasta by measuring *L*, a*, b** by using a reflectance colorimeter (CR 300 Chroma-metter, Minolta) as in Figure 2.5. The highest *L** values (brightness) were recorded in the dried maize sample and fresh noodle sample *L*. All samples with wheat straw and defatted soy flour recorded the lowest *L** values (higher brownness) which can be learned through higher value of dietary fibre and ash content (Ugarčić-Hardi et al. 2007). In another study, a range of seaweeds puree which was *E.cottoniii, G. verucossa* and a mix between them, substituted 30% proportion in the noodles formula. However, such substitution of seaweeds puree did not give any significant effect ($p>0.05$) but only to the colour and taste of the noodles (Dewi 2011).

$L*$ of instant noodles corresponds in linear to the SDS sedimentation volume and non-linearly to the salt soluble portions of flour and alcohol. Protein quality parameters verified a sequential correlation with $b*$ of instant noodles. Cooking process parameters such as oil absorption, frying (or drying) and steaming influence the colour of noodles. This was truly dictated by the negative relationship of noodle dough sheet lightness ($L*$) in contrast to positive relationship of $L*$ of cooked instant noodle with the protein content in flour. Alkaline reagents provided a yellowish tinge to the colour of the noodles. Polyphenol oxidase activity and flour ash content influences the noodle whiteness (Gulia et al. 2014).

2.3.3 Starch Gelatinization

The end use of starches includes cooking, brewing, textural, and digestive properties, which can be significantly affected by the gelatinization. Starch loses its crystallinity during gelatinization, such that process is analogous to melting. The parameters are the onset temperature, the peak temperature and the temperature range over which gelatinization occurs along with the heat of gelatinization. From the gelatinization process and the fat/amylose interactions of starches, the cooking, digestive and textural properties of food products containing starches shall be understood (Sichina 1992).

During food processing, starch mainly undergoes nonchemical changes. Among the nonchemical transformations that are dealt with are including physical damage to starch, gelatinization, and amylose-lipid complex formation (Delcour et al. 2010). Indeed, starch gelatinization has become relevant in many food applications. There was a study on the technological applications of starch gelatinization particularly the rheological properties. In particular, differential scanning calorimetry (DSC) is appropriate in investigating the phase transitions of starch/water system due to the occurrence over a wide range of starch/water ratio, determination of gelatinization temperatures above 100 °C; as well as the estimation of transition enthalpies. The gelatinization of various legume starches was performed by using potato and corn starches as comparison (Biliaderis et al. 1980).

Under thorough inspection through differential scanning calorimetry, well-rested dough subjected to steaming has a higher amount of starch gelatinization than the unrested dough. The inadequate uniform water distribution during steaming has prevented starch full gelatinization. At the same time, the unrelaxed gluten merely restrained starch swelling. Starch generally gelatinizes until the temperature of 84 °C though the moisture is more than 70% (Wu et al. 1998). Therefore, the gelatinization temperature of noodles was higher than 84 °C. This is true that noodles were partially gelatinized prior to regular steaming. The gelatinized starch plays an important role in determining the viscoelastic texture and rehydration rate of the finished noodles. Since steaming was not sufficient to escalate the degree of starch gelatinization, boiling may somehow improve the rehydration rate of the product (Hou 2010).

In this previous study, producing hot-air dried instant noodles takes degree of starch gelatinization into account. Starch gelatinization affected noodle firmness, viscoelasticity, and rehydration rate whereby it is primarily determined by the steaming process (Gulia et al. 2014). As the water moves out, the noodle did not burn as the water is intended for the purpose of cooking the noodle core. Therefore, plenty heat is supplied in order to bound water to accomplish starch gelatinization (Fu 2008).

The laksa noodles subjected to five particle sizes of ≤63, 80, 100, 125, and 140 µm which was made using dry milling were investigated in terms of its physicochemical properties. Rice flour of lowest particle size had the highest peak viscosity, and water absorption index but the lowest gelatinization temperature. In fact, the lowest size passed along the onset gelatinization temperature quicker and illustrated superior thickening properties than the flour of larger particle size (Nura et al. 2011).

The study on substituting sweet potato flour at the levels of 0, 10, 20, and 30% into wheat flour was reported. The increasing level of sweet potato flour in instant pasta formulation increased total carbohydrate, ash, crude fibre, and starch contents but decreased the protein level. Mixing pasta dough at increased temperature range of 50-80 °C has enhanced the colour of the pasta, by inactivating polyphenoloxidase. This has increased the strength of pasta which resulted in lower starch gelatinization and cooking time due to pre-cooking occurrence at the dough mixing process (Taneya & Biswas 2014).

The gelatinization temperatures and glass transition of rice flour retrieved from DSC were 75 °C and 58 °C, respectively. Such temperatures were determined to find out the annealing and high moisture treatment conditions in the experiment. The heat capacity (ΔC_p) of rice flour is distinctly different between the gelatinized and glassy states with ΔC_p of 15.07 J/g and 0.03 J/g respectively. The starch gelatinization endotherm is defined by the amorphous and crystalline transition. On another note, the glass transition endotherm is merely restricted to amorphous area which surpasses melting process (Cham & Suwannaporn 2010).

Pre-gelatinization is a process to convert the starch into a state that can be consumed in ease after just 2 or 3 minutes of cooking. Both fried and non-fried noodles are pre-gelatinized, with different methods to fix the process. The noodles are cooked in boiling water until the gelatinization zone has proceeded across the noodles. This process induces gelatinization, enhancing the digestibility and texture of the noodles. In the non-frying method called gelatinized dried, the noodles are dried in metal frames for the least 30 min at around 80 °C (Kim et al. 1988).

However, soaking temperature below starch gelatinization is recommended to minimize leaching of solids (Luh et al. 1980). The starch behaviour in water is concentration and temperature dependent (Whistler & Paschall 1967). Higher temperature increased water uptake in which starch granules collapse, which leads to solubilisation of amylopectin and amylase in creating a colloidal solution. This is because temperatures above the gelatinization temperature of starch (approximately 60 °C) can result in loss of crystallinity, increased diffusion of water into granule, increased hydration, and swelling power of starch (Antwi Godfred Isacc 2011).

As anticipated, the drying rate increased with the temperature increment. The increasing drying rate deemed to slightly reduce the starch gelatinization of instant noodles that eventually promoted higher rehydration time of dried noodle. This is due to the increased porosity of noodles at higher temperature that triggered water penetration (Pronyk et al. 2010).

The incomplete gelatinization of starch in the rice noodles was found to proceed during drying. The complete gelatinization of rice flour occurs when the moisture content was more than 70% (by weight) and the onset gelatinization temperature was 61.95 °C at 30% moisture content and 67.78 °C at the moisture content of 50%. In fact, the moisture content of rice flour slurry and fresh rice noodles was 60% and 51.49 % respectively. Therefore, it was agreed that the starch gelatinization of fresh rice noodles was incomplete which was gelatinized during drying at 70 and 85 °C (Kongkiattisak & Songsermpong 2012).

In a study by Zhang et al. (2011), all pasta samples were fully gelatinized above gelatinization temperature, prior to any drying air temperature, which halted water diffusion. By soaking in the gelatinization temperature range of 52-63°C, high temperature dried pasta had the lowest water absorption rate. This is due to the layer of gelatinized starch which restricted water penetration into the pasta.

Noodle was vulnerable to various changes, such as starch gelatinization and protein polymerization during the dehydration process at high temperature with the presence of moisture. Drying the noodles over 75 °C significantly increased ($p < 0.05$) onset temperature (T_o) and peak temperature (T_p) because of the derived gelatinized starch due to the process. Therefore, high temperature merely induced higher water removal rate in noodle samples, which led to a compact structure of lipids and starch. In this case, more energy with higher temperature is required for complete starch gelatinization. Starch gelatinization was not detected as depicted from its enthalpy values (ΔH) at the medium temperature drying. The high temperature drying significantly decreased the enthalpy values due to partial gelatinization of noodles (Li et al. 2016).

Physicochemical properties of starches isolated from Colorado grown legumes were examined to find a feasible, less expensive source for preparing starch noodles. It was found that starches of mung bean noodle did not leach into cooking water before further gelatinization to form a gel network-like structure. The gelatinization temperature of mung bean starch granules was in the range of 62-73 °C (Sung & Stone 2004). The gelatinization temperatures of mature maize and immature maize (MM and IM) and potato tuber (PT) starch, exclude PT-FD starch, in the range of 64 °C to 78 °C. The FD reduced ($p < 0.05$) both the ΔH values and gelatinization temperatures of all samples significantly, in particular the PT starch granules. The relatively lower values of ΔH and gelatinization temperatures suggested that oven drying induced less textural changes than FD (Zhang et al. 2014).

In another study, the gelatinization peak of mung bean starch fell in the range of 63.3 °C to 83.5 °C. The gelatinization peak of mung bean starch was similar to tapioca starch in the range of 61.5 to 82.2 °C. The onset gelatinization temperature of tapioca starch (63.8 °C) was lower than mung bean starch (68.0 °C). Thus, the enthalpy change of the mung bean starch (7.6 J/g) was slightly lower than the tapioca starch (8.0 J/g) (Kasemsuwan et al. 1998). Therefore, potato and tapioca starch are usually added in preserving the high quality of instant noodles. These starches have relatively rapid swelling characteristics, low gelatinization temperature and high viscosity (Yu 2003).

Recently, the gelatinization of starch-water systems was investigated by using differential scanning calorimetry (DSC). This technology allows starch gelatinization to be learnt in details. In addition to that, the temperature range in which gelatinization occurs and its particular enthalpy across this heat transition is determined. Thus, the behaviour of starch derivatives during gelatinization and the convenient of water and the ingredients for instance sugar and salt on gelatinization authorized promising scope of research by the usage of DSC (Starches & Wootton 1979).

Steam trigger starch gelatinization upon dehydration in which enhancing the water absorption of noodles. However, inappropriate starch gelatinization may occur due to the fat content migration to the external layer which restricted the water absorption. Of all tested samples, freeze drying product required higher force of tensile strength to stretch fat addition before it gets broken prior to further breaking distance (Gatade & Sahoo 2015).

The quality analysis of composition, protein and starch quality, and noodle-making quality was executed to learn the effects of both consumers and manufacturer's flour on instant noodles. The selected samples were the samples of five US/Canadian samples, seven local commercial wheat flours, and five Iranian hexaploid landrace. The overall gelatinization temperature was found to range from 52.6 to 70.1 °C as the heat enthalpy (ΔH) is in the range of 4.7 to 7.5 J/g (Wu et al. 2006).

2.3.4 Rehydration Ratio

Rehydration is performed by pouring a sufficient amount of hot water to the sample within specific time. Food products are usually soaked in hot water prior to consumption to determine customer acceptance which acknowledged rehydration as one of the basic element in food quality. The water absorption rate is initially higher before slowing down towards equilibrium. The factors affecting rehydration are capillaries and cavities near the surface, dryness, temperature, trapped air bubbles, amorphous–crystalline state, porosity, soluble solids, anions, and pH of the soaking water (Rahman & Durance 2002).

Rehydration ratio was calculated as the percentage in the weight of cooked noodles per the weight of dried noodles. Low rehydration rate usually causes noodles to be having coarse texture, but excessive water absorption often results in too sticky and soft texture and to the worst extent, soggy noodles (Fari et al. 2011). The morphology of dried cooked rice prior to rehydration could not be observed by observing the drying trends of rice noodles from low (50 °C) or high (120 °C) temperatures and two levels of average air drying velocity (Kongkiattisak & Songsermpong 2012).

Hot air drying produces noodles of an intact structure with slow rehydration rate in hot water. In the meantime, high porosity of the expanded noodle at the core enables prompt water penetration to induce further rehydration faster (Widjaya 2010). Steaming plays a pivotal role in the rehydration process of the particular product. Unfortunately, the slow output of the process and short of appealing taste is unable to make such noodles popular in Asia than the instant noodles (Hou & Kruk 1998).

It took 3-4 minutes of boiling instant noodle in hot water to prepare as a meal since it is pre-cooked by frying prior to packaging. The main function of steaming is to favour starch swelling before gelatinizing to a superior consumption in order to assist fast rehydration of the dried noodles. In similar note, the heat due to hot air drying or frying may gelatinize starch to create porous texture in noodles which assisted rehydration to occur faster. Such high porosity which was formed throughout the process acted as the conduit for water penetration for the purpose of rehydration. Furthermore, deep frying of noodles remove moisture, incorporate oil within the noodles and gelatinize starch before unbound water is removed to the atmosphere to create pores in the noodle structure that facilitate higher rehydration rate (Gulia et al., 2014; Hou, 2010).

Higher drying rates deemed to improve the rehydration time of the dried product (Pronyk et al. 2010). However, excessively high rehydration ratio render the noodles to be overly sticky and soggy whereby low rehydration ratio produced noodle of hard and gross texture. In overall, the noodle quality is deemed to be accepted once the rehydration ratio of rice noodles increased comparably (Thomas et al. 2014).

The noodle strands of bowl-container noodles are purposely made to be finer than the bag-packaging to assist the convenient rehydration. Adding starch to the instant noodle structure concede consistent texture and minimal rehydration time. In fact, a small amount of gums at 0.2–0.5% enhance the rehydration ability of such noodles (Fu 2008). In similar note, the effects of noodle moisture, gum and starch on the rehydration rate of cooked instant noodles were studied. Fat absorption decreased to the increment of starch addition level and moisture content. In the meanwhile, the rehydration rate increased to the increment of starch content from 0 to 6.0% and moisture content. The rehydration rate was somehow reduced by adding starch from 6.0 to 9.2% (Yu 2003).

Under several pre-treatments such as salt solution, ascorbic acid, honey, and lemon juice, banana slices were dehydrated inside a cabinet dryer randomly at 60 °C and 70 °C and the rehydration ratio was studied. The rehydration ratio was found to be minimum at 1.215 for 7 mm thick slices soaked with ascorbic acid and the rehydration ratio was maximum at 1.716 for lemon juice soaking treatment (Abano & Sam-Amoah 2011). In another study, banana slices dried at higher temperatures had higher rehydration performance compared to those dried at lower temperatures. Higher drying temperatures created a more porous structure in the banana slices, thus promoting rehydration ability (Chen 2008).

2.3.5 Sensory Evaluation

Despite the Chinese Ministry of Commerce has released the official sensory evaluation method in 1993, the scoring system face three main problems. First, the method's definitions of stickiness (noodles should not closely stick to teeth prior to chewing) and elasticity (elastic and cohesive in chewing) is often be confusing the panels to score similar characteristics. The correlation coefficient between stickiness and elasticity fell in the range of 0.70 to 0.85 in different experiments. Second, due to the difficulty in evaluating stickiness and elasticity which each are assigned unrealistic 25 point. Third, there is no sensory reference sample in evaluating the score which has made it inappropriate to cause the score inconsistency despite the panellist being well trained (Gary G. Hou 2010).

The wheat noodles were formulated with 10, 20, 30, 40, and 50 % banana flour. The sensory evaluation panels scored the uncooked and cooked noodles at moderate (Ritthiruangdej et al. 2011a). In another study, results showed that samples of breadfruit noodle had preference score of 5.60 out of 9. Sensory evaluation of konjac noodle was influenced by preparation method, with the preference of 6.6 out of 9. The highest sensory preference was 7.0 given to noodle consisting 54% pumpkin flour (Purwandari et al. 2014).

Furthermore, the instant noodles were prepared with 0, 10, 20 and 30% of sweet potato flours. This has resulted instant noodles made from 30% sweet potato flour to score the highest sensory attributes such as texture, colour, flavour, and overall acceptability in comparison to the other samples. However, equal acceptance could be observed for the noodles with the addition of 20% sweet potato flour (Taneya & Biswas 2014).

In further study, there were also significant difference ($p<0.05$) in terms of mouth feel, aroma, and texture of producing noodles from the blended flours of cassava, wheat, and defatted protein rich. Due to the experimental design, substituting 20% of wheat flour with a blend of 10% cassava flour and 10% defatted soybean flour has prepared a protein rich and satisfactory noodles (Nwosu 2015). However, the substitution of different seaweeds puree did not deliver particular significant findings ($p>0.05$) except for the colour and taste of the noodles (Dewi 2011).

In the meantime, sensory quality was evaluated for mouth feel, odour, flavour, external appearance, and total quality preference scores in the scale of 1–5. The noodles prepared from extruded maize flour, maize flour, and wheat straw supplements was evaluated with highest scores (Ugarčić-Hardi et al. 2007). Next, the sensory evaluation of taste, texture, appearance, and overall acceptability of laksa noodles prepared from small particle flour were significantly ($p<0.05$) higher than those made from large particle flour. The smallest particle sized flour has emerged as the most preferred sample (Nura et al. 2011).

2.3.6 Scanning Electron Microscope (SEM)

The rheological parameters of the noodles should reflect the textural and quality characteristics of particular noodles. Thus, the study has correlated microstructure images between the effects of ingredients in noodle formula in regards to steaming and its quality attributes (Gatade & Sahoo 2015). In fact, the microstructures of Thailand rice noodles showed the dried noodles to be in a condensed structure. Unfortunately, regardless drying conditions did not show apparent structure to the rice noodles (Kongkiattisak & Songsermpong 2012).

Microstructural changes of starch granules and protein matrix, and the presence of lipids were observed to respond to different regimes of process: addition of soaking water, and inputs of mechanical force and heat (Gulia et al. 2014). The microstructures of dehydrated noodles indicated the outcome of the added ingredients on the structure of noodles. The effect of additives and several ingredients were observed clearly at higher magnification level of 1000. For example, less compressed starch granules were particularly observed on the noodle surface which is not encased within the protein compound. The cross sectional area exhibited the internal structure to be less intact in which the molecules are loosely linked to one another, which further explained the higher cooking loss of the noodle sample. SEM observation of the 5g oil sample gave a smoother surface than the other sample. It was carefully observed at 1000× magnification that starch granules were less exposed to the air produced a less sticky surface (Gatade & Sahoo 2015).

2.3.7 Fat Content

High content of fat cause instant noodles to be susceptible to oxidative reaction due to rancidity. Frying has been the preferred present method of food preservation as non-fried instant noodles require lengthy cooking time. However, the lesser fat content in noodle drying is more appealing. Eliminating oil in the noodle drying may somehow solve the arising concerns of fat content and presence of trans-fatty acids from the hydrogenated oils in producing an easy-to-prepare and healthy food. However, the huge acceptance of dried noodles is still a big task as it should have superior eating quality with good textural properties (Gulia et al. 2014). Due to the huge potential of low fat content that air-dried instant noodles may offer so certain into-healthy-diet people may favour such noodles. The noodles also have a much longer shelf-life due to the negligible rancidity (Hou & Kruk 1998).

The increment of fat content on the substitution of seaweeds puree (ME and MC) was studied than the control noodle. In fact, 0.49% of fat content was found on the fresh wet noodles prepared from Eucheuma seaweed. Fat content was ranging from 1.22 to 2.49%, which is typically due to the available fat inside the seaweeds and the cooking oil to prevent any stickiness (Dewi 2011). The diversity levels of fat in the product due to the fat content of the raw materials (Orthoefer 1976).

The addition of oil reduced stickiness elasticity, resilience, and cohesiveness but somehow increased hardness (Gatade & Sahoo 2015).

In a separate study, the results in the food sample which was soaked for 24 hours has significantly increased ($p<0.05$) moisture, fat and carbohydrate respectively by 13.12%, 29.41%, and 0.81% in reference to the control sample (Egbuonu et al. 2014).

The residual oil content in both consumers and manufacturer's samples of five US/Canadian samples, seven local commercial wheat flours, and five Iranian hexaploid land races was found to be high. The quality analysis in terms of composition, protein and starch quality, and noodle-making quality was executed to learn the effects of different wheat flour on the oil content of instant noodles (Wu et al. 2006).

2.4 CHAPTER SUMMARY

This chapter reviews the works reported on drying characteristics, types of different drying processes subjected to the scope of study and the specified quality analysis in different types of noodles. The information gathered provides references in designing the experiments for learning the drying characteristics and the preservation of quality attributes of rice noodles.

The literature explains the application of heat pump drying and hot air drying whereby each of this process has their own advantages. Heat pump dryer is able to dry the specific material subjected at low temperature and lower relative humidity while hot air dryer can dry up almost a wide range of materials rigorously. In the meantime, freeze drying is the advanced drying method that may preserve most of the quality attributes but at the higher cost.

Furthermore, the drying procedure and quality analysis of rice noodle are outlined in the following chapter. The drying characteristics of rice noodle may be observed at the effective diffusivity values as well as the studies of quality analysis for the prediction of drying process in the improvement of drying performance.

CHAPTER 3

MATERIALS AND METHODOLOGY

3.1 MATERIAL

Rice noodle made of rice flour and water with the coating of palm oil was purchased from a similar local noodle supplier known as Koperasi JML as in Figure 3.1 around Sungai Tangkas, Selangor, Malaysia (Latitude 2° 57′ N and Longitude 101° 47.28′ E). The rice noodle sample was translucent, creamy colour of the value of L^*, a^*, b^*, c^*, and h° to be 72.0, -2.5, 1.5, 2.9, 149.6, oily and long stretch. The dimension of the specific sample of fresh rice noodle was 2 x 1 x 0.15 cm. A packet of fresh rice noodles (400 grams) was separated and half of them was pre-treated with distilled water and filtered to create two types of sample namely non-oil coated rice noodle and original rice noodle.

Figure 3.1 Sample of Fresh Rice Noodles

3.2 METHODOLOGY

The research scope of this study includes the effect of different drying techniques namely hot air drying, low temperature heat pump assisted drying and sub-zero temperature freeze drying, while product quality aspect includes texture, colour, microstructure, oil content, sensory evaluation, starch gelatinization behaviour, and rehydration ratio.

3.2.1 Pre-treatment

The pre-treatment process was performed by soaking the rice noodle in the distilled water until the oil coating seemed to disappear. The main purpose of the process is to represent the non-oil coated sample, not to literally describe zero oil sample. This process typically took 1 minute to complete. Extra care was taken to avoid the noodle to get swollen. In this study, half of the total 400 grams of rice noodles were subjected to pre-treatment by soaking in 1L of distilled water. The rice noodles were then rinsed before instantaneously subjected to drying process. The other half of 400 grams of rice noodles were subjected to drying without any pre-treatment. Three replicates according to the dimension of noodle sample were subjected to drying process whereby the other three replicates were prepared for quality analysis.

3.2.2 Hot Air Drying

Figure 3.2 shows the picture of a hot air dryer used in this study (Memmert, UNB 200). With the dimension of 400 x 320 x 250 cm (length × width × height), the temperature of the hot air oven can be controlled within the range of 20 to 250 °C with the accuracy of ± 3 °C. The drying temperature was set for 30 minutes to reach the set point before the sample is subjected to main drying. It is equipped with three adjustable drying shelves with the 32 litres volume and 28 kg weight.

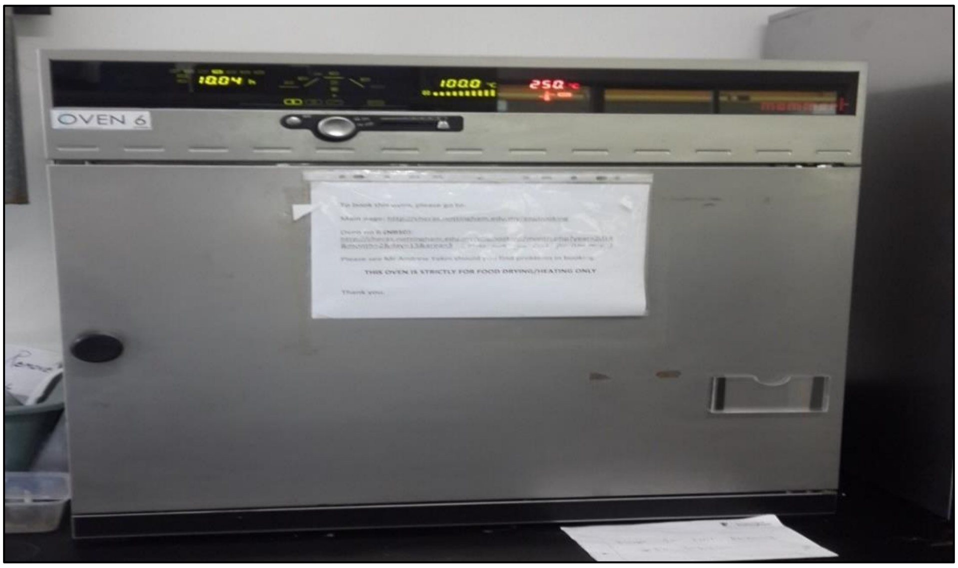


Figure 3.2 Memmert hot air oven

The rice noodles were placed in a layer to promote direct drying on two similar meshed-surface tares (0.8 m × 0.8 m each) inside the drying chamber of hot air oven dryer. The separate set of rice noodles were then placed in another layer for the purpose of quality analysis.

Fresh rice noodles were dried in a hot air circulation oven of laboratory-scale (range 20–250 °C, Memmert, Schwabach, Germany) with an accuracy of ±3 °C at the temperature of 30 °C with air circulation. The air circulation was set at a velocity of 1.401 ± 0.5 ms^{-1} and relative humidity at 20.3 to 28.6 ± 1.0 %. Prior to drying experiments, the oven was pre-heated at the selected operating conditions for about 30 minutes in order to reach steady-state. During drying process, the mass of the sample was measured in an interval of 10 minutes during the initial process and it spanned longer towards completion of the drying process up to 30 minutes per interval. The total drying times for hot air drying with air circulation were determined once the noodles have reached equilibrium moisture content (EMC) by extending the drying process until the constant mass of drying sample was observed. The process was repeated for the temperatures of 60 °C and 90 °C.

3.2.3 Heat Pump Drying

Figure 3.3 illustrates a schematic diagram of a heat pump dryer. The pilot scale heat pump dryer was supplied locally by I- Lab Sdn. Bhd. (Selangor, Malaysia). It comprises of a heat pump system of 2 drying chambers with meshed trays to contain the drying products. The system operates in a closed loop whereby there is no air exchange between the drying air with the surrounding. The dryer uses R22 refrigerant as the working fluid.

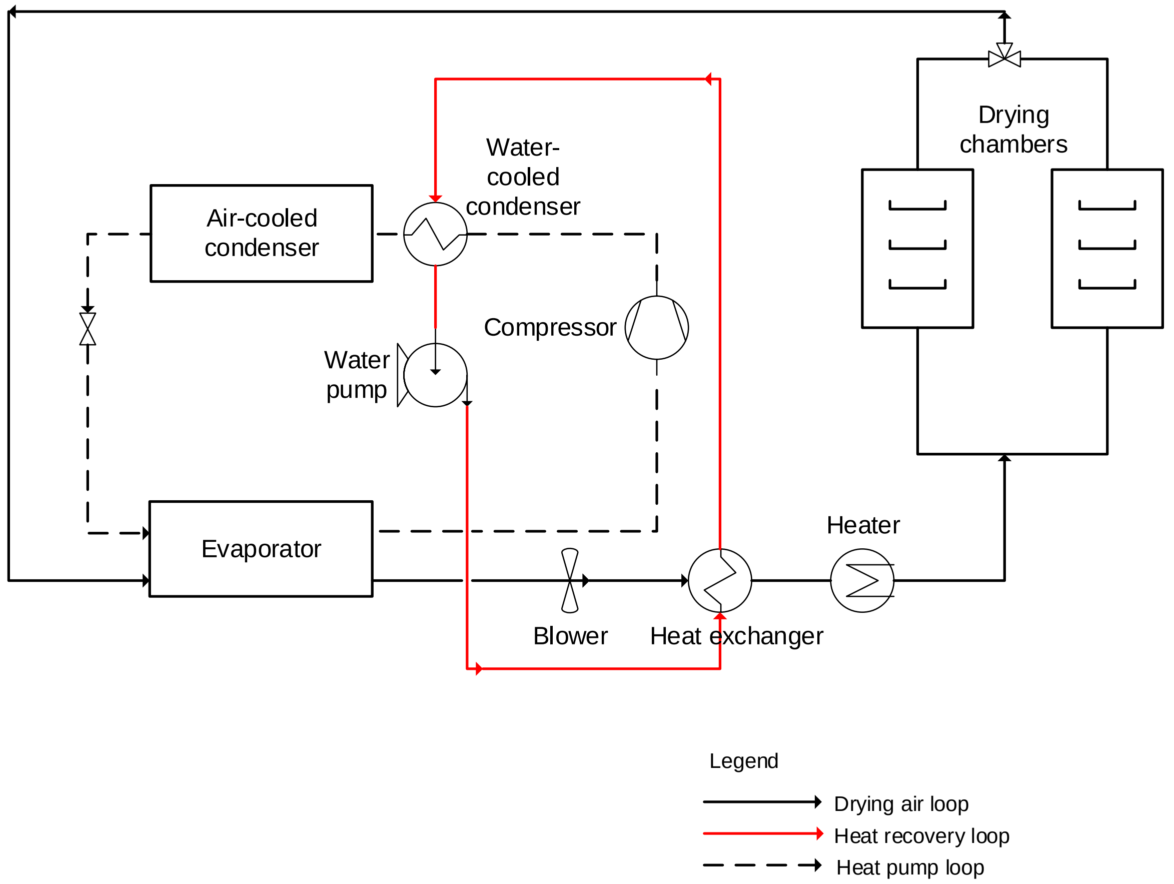


Figure 3.3 Schematic drawing of a heat pump drying system (Hii et al. 2012)

There are three sections built in the drying system namely heating, heat recovery loop and drying air which flows in a direction perpendicular to the product tray, and a heater is introduced to increase the air temperature. Therefore, there are two operating temperatures subjected to the usage of the heater with the accuracy of ±3 °C. One operating temperature is when the external heater is switched on, the other one is the operating temperature when the heater is switched off.

The total built-up dimension of the dryer is 2.3 m × 1 m × 2.1 m. The dryer is shown in Figure 3.4. It has two drying chambers measured at 0.33 m × 0.33 m x 0.95 m each. In this study, one drying chamber was utilized throughout the study for the drying kinetics and the other one was not used. The two drying chamber setting allows the study of intermittent drying but intermittent drying is not the scope of this study. Therefore the second drying chamber is not used.

Figure 3.4 Heat pump drying system

A packet of fresh rice noodles (400 grams) which half of them are subjected to pre-treatment was arranged horizontally on the wire screen tray with a size of 0.27 m x 0.23 m inside the drying chamber, perpendicular to the air flow. The dryer consists of two drying chambers measuring 0.95 m x 0.33 m x 0.33 m and the samples were put inside one chamber only. The operating temperature fluctuated as it was subjected to the ambient conditions and the heater set-up. If the heater is turned on, the drying chamber operates at drying temperature of 50 °C whereby as the heater is turned off, the drying operates at the temperature of 38 °C. The air flow velocity is measured at 4.6 ms^{-1} ± 0.5 and relative humidity is in the range of 18.2 % to 25.2 % ± 1.0.

The drying was carried out at the temperature of 38 °C in a continuous mode. The mass of the sample was weighed using an electronic balance (model GF-3000, range 0.5 g–3100 g, with an accuracy of 0.01 g, San Jose, CA) at the pre-determined intervals until EMC is achieved. A similar heat pump drying process was repeated at the temperature of 50 °C.

3.2.4 Freeze Drying

The rice noodle samples were kept inside a deep chest freezer (*Mistral, Khind (M) Sdn Bhd, FZ-220*) overnight at around -18 °C prior to freeze drying. The vacuum pump was turned on for around 30 minutes. The frozen samples were then subjected to freeze drying. The operating conditions were set to run for 24 hours under two different pressures which are 0.256 kPa (-10 °C) and 0.0120 kPa (-40 °C) for main freeze drying. The final drying is not necessary for rice noodle.

Figure 3.5 shows the image of the freeze dryer (*Martin Christ Alpha 1-2 LDplus*) used in this study. The temperature range of the freeze dryer is from 0 °C to -50 °C. Weighs at 28 kg, the dimension of the freeze dryer is 315 x 345 x 460 mm. It has 3 maximum removable drying shelves, each with 200 mm diameter. The ice condenser capacity is up to 2.5 kg with the performance of 2kg/24h. The condenser temperature of -55 °C enables the drying of any aqueous products. The complete duration of the freeze drying process can range from at least 12 hours.

A vacuum pump is attached to the freeze dryer. The vacuum can be set from 6.110 to 0.011 mbar. After the freezing, the system should then be taken through a warm-up/cool-down phase. The vacuum pump can warm up with the pressure control valve closed, and in this way improves its performance and its ability to withstand water vapour. The warm up should take between 15 and 30 minutes to allow overall vacuum build-up. Before that, the drying sample should be frozen overnight using a *FZ-220* deep freezer supplied by *Mistral, Khind (M) Sdn Bhd.* before it is subjected to freeze drying.

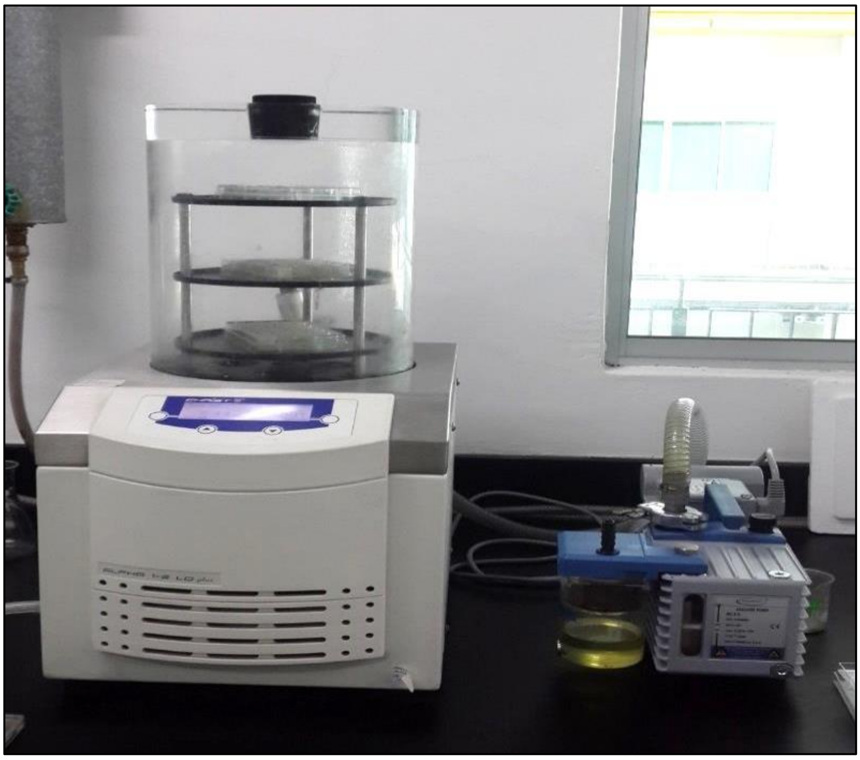


Figure 3.5 Freeze drying system

3.2.5 Moisture Content

Rice noodle samples were retrieved periodically from the drying tray and weighed. Moisture content (MC_{db}) in dry basis was determined periodically based on the weight of the drying samples according to Equation 3 (Reeb et al. 1999).

$$MC_{db} = \frac{M_t - M_{ds}}{M_{ds}} \ x \ 100 \ (\mathrm{g\ H_2O\ g^{-1}\ dry\ solid}) \qquad (3)$$

Subscripts $_t$ and $_{ds}$ refer to weight at time *t* and dry solid, respectively. Dry solid weight, M_{ds} was determined by drying similar sample in a convective oven dryer at 105 °C for at least 24 hours.

3.2.6 Drying Rates

Drying rate is obtained by the slope of moisture removal tangents at *dt* as (Khani Moghanaki et al. 2013):

$$N = -\frac{Mds}{A}\frac{dMC_{db}}{dt}(\text{g H}_2\text{O per m}^2.\text{minute}) \quad (4)$$

N is the rate of water evaporation by dry basis, *A* is the exposed cross-section area for drying, and M_{ds} is the bone dry solid weight. In this case, the drying rate, *N* is then expressed in g H_2O per m^2.minute. Negative sign is because moisture content decreases over time.

3.2.7 Fick's Second Law of Diffusion and Effective Diffusivity

The effective diffusivity D_{eff} is determined by using the analytical solutions of Fick's second law. According to Fick's Second Law, the partial differential equation that describes this model is given as (Johannesson 1998; Pedro I. Alvarez 1986):

$$\frac{\partial m}{\partial t} = \frac{\partial}{\partial x}\left(D_{eff}\,\frac{\partial m}{\partial x}\right) \quad (5)$$

where *m* is the moisture content (g H_2O /g dry solid), D_{eff} is the effective diffusivity (m^2/s). Since drying is a moisture removal process, the mechanism of moisture transport may occur throughout the drying process. In this research, effective diffusivity (D_{eff}) is the combined diffusivity of different types of diffusion that occur throughout the entire drying process.

3.2.8 Moisture Ratio

As moisture ratio (*MR*) is used as a dependent variable in defining the behaviour of the drying process, it may be described by taking the value of $MC_{db,t}$ which is moisture content at time t, M_e as the equilibrium moisture content and M_i as the initial moisture content. *MR* is determined by using equation 6 (Bakal et al. 2010).

$$MR = \frac{MC_{db,t} - M_e}{M_i - M_e} \quad (6)$$

Before that, these assumptions should be made available: i) the material has constant diffusivity, ii) the material has uniform moisture distribution, iii) surface moisture of the material equals to the equilibrium moisture content. If the diffusivity is assumed constant in a certain moisture range, integration of (5) gives MR for the infinite slab by using equation (7):

$$MR = \frac{8}{\pi^2}\left\{ e^{-D_{eff}t(\frac{\pi}{l})^2} + \frac{1}{9}\, e^{-9D_{eff}t(\frac{\pi}{l})^2} + \frac{1}{25}\, e^{-25D_{eff}t(\frac{\pi}{l})^2} + \ldots . . \right\} \tag{7}$$

With *l* as half thickness of the slab and D_{eff} as effective diffusivity of the material. For sufficiently long drying time of infinite slab objects with constant effective moisture diffusivity, only the first term in Equation 7 is used which is thus can be simplified to the following equation 8 (Rizvi 1986; Karina 2008):

$$MR = \frac{8}{\pi^2}\left(e^{-D_{eff}\left(\frac{\pi}{l}\right)^2 t} \right) \tag{8}$$

Linearization of equation 8 gives the following equation:

$$\ln MR = \ln \frac{8}{\pi^2} - D_{eff}\left(\frac{\pi}{l}\right)^2 t \tag{9}$$

Linear graph can be plotted as ln *MR* versus time, *t*, and the slope of the line is:

$$slope = -D_{eff}(\frac{\pi}{l})^2 \tag{10}$$

The effective diffusivity of the material can be expressed in terms of activation energy, E_a and temperature T_a using the Arrhenius equation as given by the following equation (Madamba 1996; Henderson 1961; Crisp 1994):

$$D_{eff} = D_0 \exp\left(-\frac{E_a}{RT_a}\right) \tag{11}$$

Linearization of equation 11 gives the following equation with *R*= 8.314 J / mol. *K* as the universal gas constant and T_a as the consistent temperature at *a*.

$$\ln D_{eff} = \left(-\frac{E_a}{RT_a}\right) + \ln D_0 \tag{12}$$

The slope of linearization gives the value of activation energy (E_a). Meanwhile, the intercept of the graph gives the value of initial diffusivity (D_0).

3.2.9 Scanning Electron Microscope (SEM)

Samples were cut approximately to the scanning area at the dimension of 0.4 cm x 0.2 cm. The conductive adhesive (carbon tape) was attached to the specimen holder (aluminium stub) and the observation was done through SEM at different magnifications of 50, 800, 2000, and 5000.

In this study, FEI Quanta 400 FEG in Figure 3.6 was employed to study the microstructures of a sample. The FEI Quanta line included six variable-pressure and environmental scanning electron microscopes (ESEM™). The size of motorized stage was at 50mm, 100mm, and 150mm and the motorized z-range changes at 25mm, 60mm, and 65mm respectively. With the quick warm up times, the Quanta line of scanning electron microscopes was truly adaptable and was a very high end technology instrument. It has three modes consists of high, and low vacuum and ESEM to simply accommodate wide range of samples of any scanning system. Each electron scanning should take at least 20 minutes prior to each particular magnification.

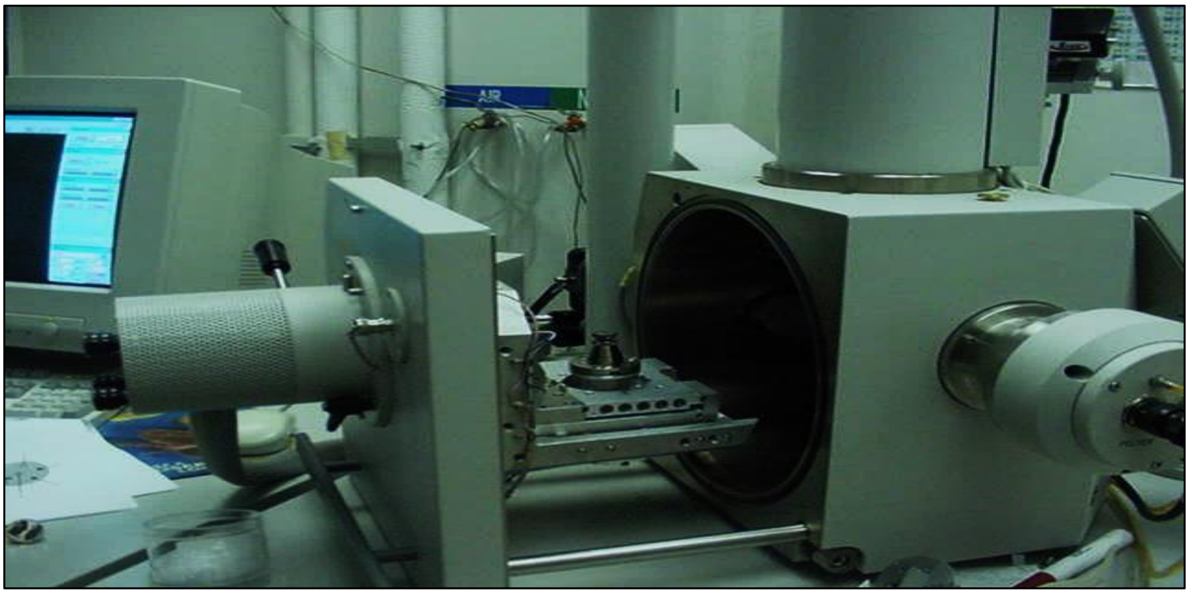


Figure 3.6 Scanning Electron Microscope

Electron beam was produced at the highest point of the microscope by an electron gun (Purdue University 2014). The electron beam completed a vertical way the magnifying lens, which was held inside a vacuum. The pillar went through electromagnetic fields and focal points, which centred the bar down toward the sample. Once the pillar hit the sample, electrons and X-rays were ejected from the specimen. Detectors assembled these X-rays, backscattered electrons, and secondary electrons to simultaneously convert them into a signal that was sent to a screen to finally produce the final image (FEI Company 2006).

3.2.10 Colorimeter

The colour of fresh and dried rice noodles was analyzed using a handheld colorimeter (Lovibond, LC100/SV100 Integrated Package, England). As outlined by the International Colour Standardization body, colour parameters were characterized into three groups viz. The colour of the sample was measured in terms of $L*$ (light–dark spectrum, range from 0 to 100), $a*$ (green–red spectrum, range from -60 to +60), and $b*$(blue–yellow spectrum, range from -60 to +60), respectively. The colour analysis of dried sample was scanned at three arbitrary areas to eventually define the average values (n=3) by taking fresh noodles as the reference value. Total colour change (ΔE) was calculated using Equation 13 (Wyszecki, 2000):

$$\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2} \tag{13}$$

ΔL, Δa, and Δb represent $(L_o\text{-}L*)$, $(a_o\text{-}a*)$ and $(b_o\text{-}b*)$ where L_o, a_o, and b_o are the initial colour measurements of fresh samples and $L*$ $a*$ and $b*$ are the colour measurements of the dried samples.

The image of a colorimeter used in the study is given in Figure 3.7 (LC-100 Lovibond). Being handheld, the colorimeter shot images of sample using 8 different visible illuminations and 1 UV LED (9 bands) for more detailed colour dimension with the unique imaging technology: 45/0 optical geometry and image capture technology.

Figure 3.7 Colorimeter

3.2.11 Texture Analyzer

TA-XT Texture Analyzer (Stable Micro Systems Ltd., Vienna Court, Surrey, UK) by attaching Warner-Bratzler blade set to the analyzer probe for shear was used to measure the noodle texture. The noodle texture was determined by placing the dried noodle on the plate and sheared. In cutting test, hardness was the force required (the first peak force) to break the sample by applying a maximum force of 5500g on the sample. The acceptable force to break noodles was in the minimum range of 500g to 700g. Triplicates were utilized as a part of each drying process and set on an average (S. Bharath Kumar et al., 2013).

Figure 3.8 showed the visual of a texture analyzer used in this study (TA.XT*plus* Texture Analyser from Stable Micro Systems). It was able to measure any physical product characteristic such as hardness, fracturability, adhesiveness, gel strength, and extensibility. The probe used in the study was Warner Bratzler Blade Set with 'Rectangular slot blade.

The blade should shear the sample up until it slightly reaches the heavy duty platform with aluminium plate (TA-90). It determined the utilization of a blade edge machined to a 1mm level over the cutting edge, which measured the power required to cut the strands of noodles situated on the plate. Firmness was defined as it works in grams-centimetre required to shear one piece of noodle. The maximal cutting force per unit area is also used as an indicator of noodle firmness and the results of both tests were correlated with the data obtained by hardness tests.

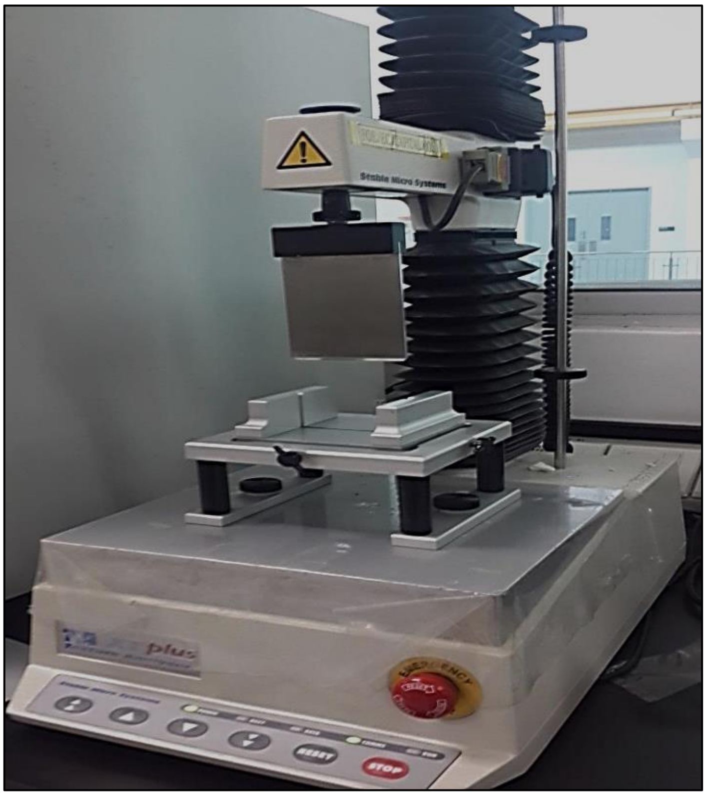


Figure 3.8 Texture analyzer blade set

The hardness test measured the force (in grams) required as in Figure 3.9 to cut a slice of noodle. The test cell set made up of a 3 mm-thick steel blade with a flat cut lower edge to discard friction. The noodle sample was placed on the table, under the flat blade it cut through as the blade moved down with a constant speed through the slit of the table (assay parameters were: pre-test speed: 2.0 mms^{-1}; test speed: 2.0 mms^{-1}; post-test speed: 10.0 mms^{-1}).

Down stroke distance was: 15.0 mm (it can vary between 25 and 35 mm, as the probe should be able to cut the sample completely). The resistance of the noodle sample to cutting was recorded every 0.01 s and plotted by a computer in a force–deformation plot. The parameter recorded the highest peak of the curve as the maximum shear force, which signified the maximum resistance of the sample towards shearing. Each sample was measured anonymously at the smooth surface in three replicates and got into an average (Smewig 2014).

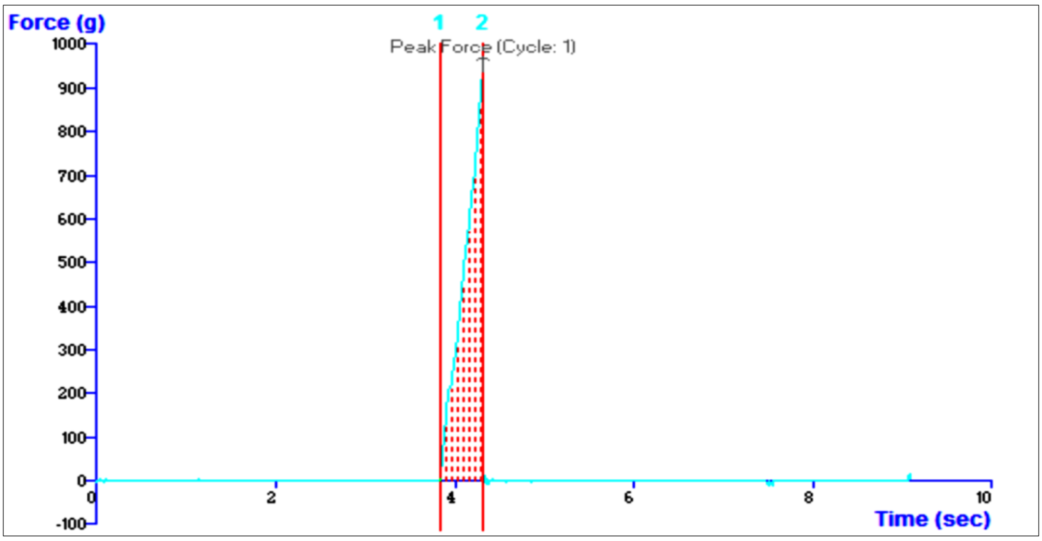


Figure 3.9 Cutting force using Warner-Bratzler blade set

3.2.12 Fat Content Analysis

A 10 gram of well grinded dried noodle was placed in a porous thimble and was inserted in the Soxhlet extractor. The extracting solvent (petroleum ether) was placed in a dried flask. The empty flask was then weighed. The solvent was then heated. When it volatilized, it condensed before it is recollected in the extractor housing the porous thimble. At that point, the solvent was then mixed with the noodle sample, the fat was dissolved out and eventually siphoned back into the original flask as shown in Figure 3.10.

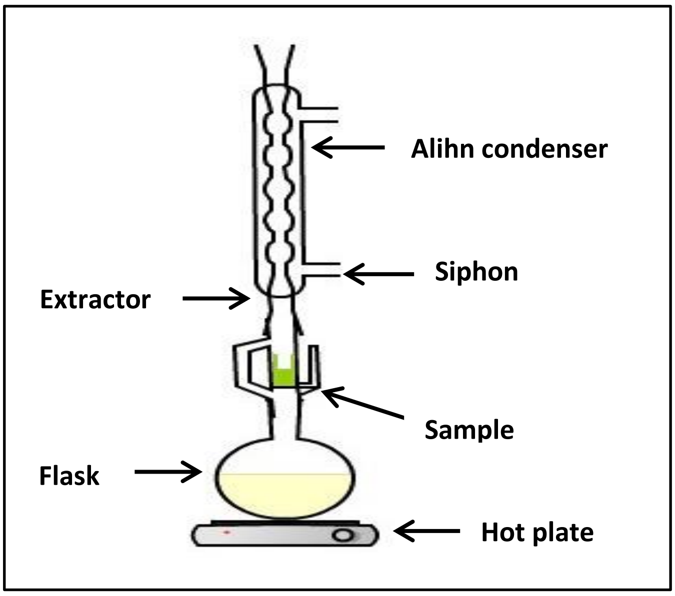


Figure 3.10 A schematic representation of a Soxhlet extractor

The process was repeated periodically for about 8 hours, after it was assumed that all the fat has been extracted from the sample and present in solution in the flask. Removal of the solvent by rotary evaporator from the round bottom flask left the fat as a residue. Round bottom flask was inserted into the oven at 105 °C for 15 minutes and then cooled in desiccators in order to determine the amount of fat inside it. The round bottom flask was then reweighed and the increase in flask weight in comparison to the empty flask was regarded as the weight of fat present in the original food. The last step was repeated just until constant weight is achieved.

By taking W as the weight of sample in grams and weight of oil as M in grams, the percentage of oil in a sample is determined by calculating:

$$\%\, of\ oil = \frac{M}{W} \text{ x } 100 \tag{14}$$

A complete set of FAVORIT® Soxhlet extraction glassware as in Figure 3.11 consists of a round bottom boiling flask, Soxhlet extractor, Allihn condenser, a siphon tube, several siphon clips, a consistent heat and water flow and a thimble. It is done in 3 replicates to get optimum accuracy. Each extraction should take at least 8 hours.

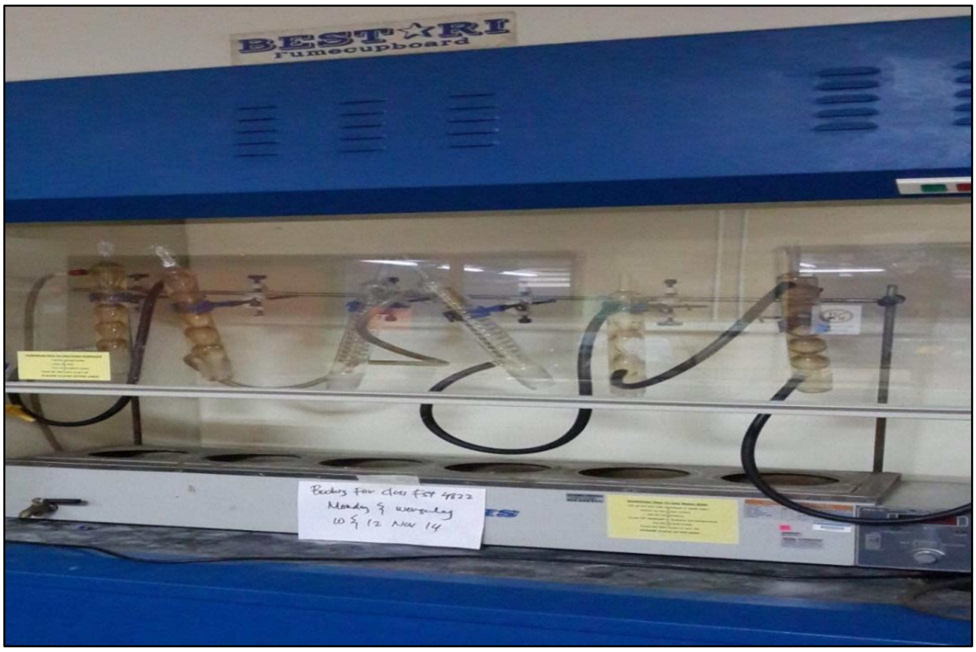


Figure 3.11 FAVORIT® Soxhlet apparatus

3.2.13 Sensory Evaluation

Figure 3.12 shows one of the sensory evaluation sessions carried out for the sample testing. 40 panels were selected to perform the sensory evaluation test in one time. Prior to the sensory evaluation test, the panels were trained by evaluating commercial rice noodles to get used with the rating scale, and the terminology used for each criteria and sensory attributes of noodles (Sandhu et al. 2010).

All dried noodle samples were prepared for the sensory evaluation test by boiling them using 1 L hot distilled water for 5 minutes. Short rehydration time was chosen as this is the expected cooking time for instant noodles. After the boiled noodle was drained, the sample were then stored for 10 minutes in tightly covered plastic food containers prior to testing. The rehydrated noodle (2g) was served in plain serving within the specific cooking time despite having fully rehydrated or not. In this study, the affective type of evaluation was employed by adopting hedonic scale to determine the sensory attributes or also known as organoleptic properties.

Figure 3.12 Sensory evaluation test

Cooked sample of plain noodles were evaluated for colour, elasticity, aroma, surface smoothness, textural smoothness, and taste by 40 trained panellists using five-point hedonic scales. The panelists utilized the line scale system to score the perceived intensity of the respective sensory attribute, with 0 for the least intensity and 5 for the highest intensity. Each panellist assessed all samples (identified by unique two codes) in a balanced sequential order with prior knowledge on the fresh rice noodle sample. Table 3.1 shows the list of the sensory attributes and the defined guidelines of the hedonic scales (Gary G. Hou 2010).

The scores from line scales were then manually translated to numbers by determining the location of particular mark on the scale. The individual attributes' score were then tabulated based on the allocated weightings as follows: colour (20%), surface smoothness (15%), textual smoothness (15%), oil/fat content (10%), elasticity (25%), and taste/flavour (15%) (Fu 2008).

Colour attribute is observed by visual. Meanwhile, surface smoothness, textural smoothness, elasticity and taste scores were determined by eating the food sample. In the meantime, oil/fat content was determined by the oil smell, glass shading feature and tangibility. Further, the panellists were asked to indicate their intention to purchase and their first impression of the cooked noodles as compared to dried noodles (Ritthiruangdej et al. 2011b).

Table 3.1 The sensory evaluation scoring sheet

ATTRIBUTES	**DEFINITION**	**RATING 1 2 3 4 5**
Colour	The physical colour appearance	dull, pale → bright, cream
Surface Smoothness	The smoothness of the external surface of the noodles	rough surface → smooth surface
Textural Smoothness	The smoothness of the texture within the noodles	low degree of internal smoothness → high degree of internal smoothness
Aroma	The percentage of oil aroma on the noodles	less likely → more likely
Elasticity	A level of chewiness and stretchability of a noodle	low degree → high degree
Taste	The sensation of flavour perceived in the mouth and throat on contact with a noodle	slight → intense

3.2.14 Differential Scanning Calorimetry (DSC)

In this study, the DSC 4000 System, by Perkin Elmer (Figure 3.13) was utilized for the determination of starch gelatinization behaviour. The system consisted of a single furnace, heat flux DSC, a cryofill with the chamber gas of Helium and Nitrogen as well as the Pyris software. The temperature range of the system is from -100 °C to 450 °C. The electrical capacity of the system is 100-240V/50-60Hz.

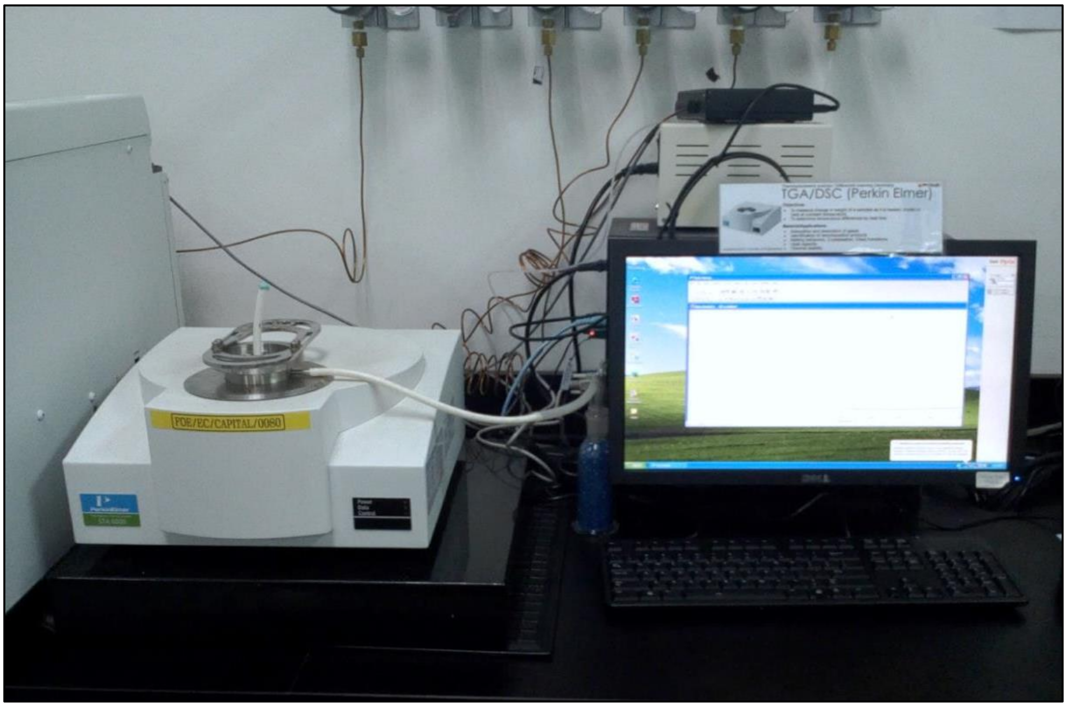


Figure 3.13 Differential Scanning Calorimetry by Perkin Elmer

First of all, a sample pan lid and bottom from their boxes were carefully removed by using tweezers. The sample was inserted into the sample pan lid. The sample weight was electronically measured from the system.

In the Pyris Manager software, the Method Editor window was entered and the details were filled in accordingly. The method to learn about the heat capacity of the noodle was created by entering the starting and final temperature to be 30 °C until 500 ^{0}C as well as the heating rate at 10 °C/min. The scanning may immediately run prior to switching the gas.

The estimated experiment duration was displayed, in generally 50 minutes based on the noodle sample. When the scan is complete and the instrument has cooled off the sample was then removed. The DSC results and graph was retrieved and analysed to determine the heat capacity of the sample and the starch gelatinization temperature (Sichina 1992).

3.2.14.1. Determination of Heat Capacity

Heat capacity is an important material property for food products. It is defined by the amount of thermal energy needed to raise the thermodynamic system by one degree. Heat capacity can be affected by many of the state variables that describe the specific system. In a DSC, the computer automatically plots the difference in heat flow against temperature. So the heat absorbed by the polymer matrix is plotted against temperature, as given in Figure 3.14.

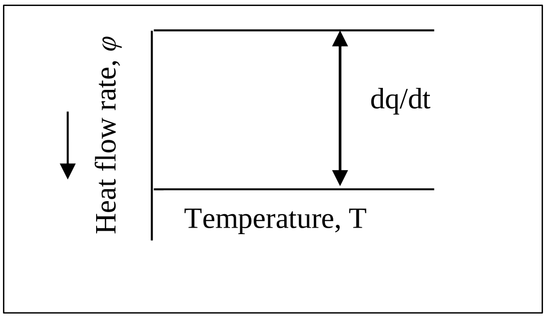


Figure 3.14 Heat flow rate as measured by DSC

The heat flow rate is shown in units of heat, q supplied per unit time, t

$$\varphi = \frac{dq}{dt} \tag{15}$$

The heating rate, β, is the time rate with the change of temperature, T

$$\beta = \frac{dT}{dt} \tag{16}$$

The heat capacity C_p, is the heat flow rate, φ, divided by the heating rate, β

$$\frac{\varphi}{\beta} = \frac{dq/dt}{dT/dt} = {}^{dq}/_{dt} = Cp \tag{17}$$

From the plot in Figure 3.14, DSC measured the heat capacity and the value of gelatinization temperature at different gelatinization stages which will be explained in the discussion further (Suchitra 2004).

3.2.15 Rehydration Ratio

The rehydration test was performed following the method of Zhou (2013) with some modifications. Noodles (approximately 3 g) were placed in a strainer dipped into a container containing 250 mL of boiling water at 100 °C and were cooked for 1, 2, 3, 4, and stopped at 5 before continuing with 6, 7, 8, and 9 minutes towards full rehydration. Then the strainer with cooked noodles was soaked and swirled several times in water (25 °C).The rehydration ratio was determined as weight of rehydrated noodle divided by weight of dried noodle. The rehydration experiments were done in triplicate and the ratio values in Section 4.34 were taken as the average.

3.2.16 Statistical Analysis

Statistical analysis was conducted by analysis of variance (ANOVA) one way using the general linear model (Minitab 16.0). The data were analysed using the ANOVA module and Tukey's procedures by assuming equal variance to detect the differences among treatments. Comparisons between the indices relative to different treatments were conducted using ANOVA, and significance of difference was defined at $p < 0.05$ in colour interpretation, textural determination, fat content, sensory evaluation, starch gelatinization behaviour, and rehydration ratio.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 HOT AIR DRYING OF RICE NOODLES

4.1.1. Influence of Drying Parameter on Drying Kinetics

The weight of rice noodle subjected to hot air drying at different drying temperature of 30, 60, and 90 °C was measured until no measurable weight loss was observed. Table 4.1 shows the time required for total drying duration to arrive at the equilibrium moisture content for rice noodles. The drying curves are illustrated in Figure 4.1. The moisture content of rice noodle subjected to hot air drying at 90 °C falls rapidly to explain faster moisture reduction to further describe shorter drying time. The results have proven the fact that drying temperature is a dominant factor in order to shorten the drying time (Ong & Law 2011).

From Table 4.1, it is learnt that the increasing drying temperature recorded shorter drying time. Indeed, higher drying temperature eventually accelerates the drying process by increasing the rate of drying. In specific, hot air drying at 90 °C had the shortest drying time compared to the other drying parameters (30 °C and 60 °C). In fact, high drying temperature of 90 °C with the low humidity of 15.3 % facilitated faster drying process.

In the meantime, pre-treatment slightly reduced the drying time. Hot air drying of non-oil coated rice noodle at 30 °C took 1380 minutes to reach the equilibrium whereas the original rice noodle took 1440 minutes to complete. On the other hand, the hot air drying of non-oil coated rice noodle at 60 °C took 360 minutes to reach equilibrium whereas the original rice noodle took 420 minutes. Finally, hot air drying of non-oil coated rice noodle at 90 °C took only 110 minutes to reach equilibrium and original rice noodle took 220 minutes.

This is due to the fact that pre-treatment which involves noodle washing whereby oil coating due to prevent microbial spoilage is removed in the noodle sample. The abundance of moisture due to pre-treatment was indicated by higher initial moisture content in non-oil coated noodle sample. Therefore slightly shorter drying times occurs in the non-oil coated noodle due to faster moisture mitigation from the external layer to the atmosphere compared to the external layer of oil in the original noodle.

Table 4.1 The time required to reach the equilibrium moisture content with respect to different hot air drying process parameters

Temperature (°C)	**Relative Humidity (%)**	**Pre-treatment**	**Drying Time (minutes)**	**Equilibrium Moisture Content (g H_2O g^{-1} dry solid)**	**Critical Moisture Content (g H_2O g^{-1} dry solid)**
30	28.6	Non-oil Coated	1380	0.168	0.179
		Original	1440	0.167	0.180
60	23.3	Non-oil Coated	360	0.067	0.229
		Original	420	0.078	0.276
90	15.3	Non-oil Coated	110	0.029	0.224
		Original	220	0.027	0.193

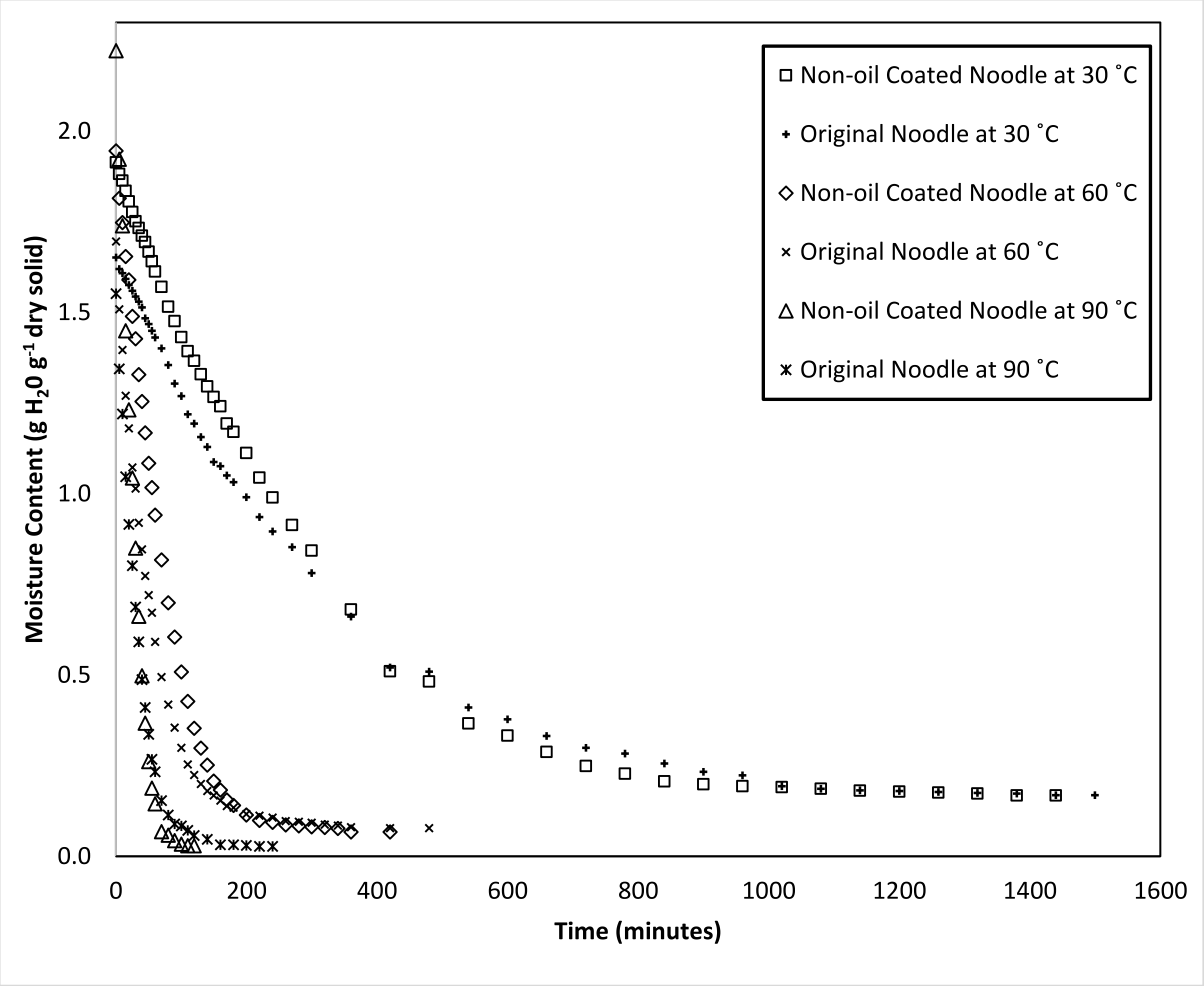


Figure 4.1 The moisture content against time of the hot air drying of rice noodles at various drying treatment

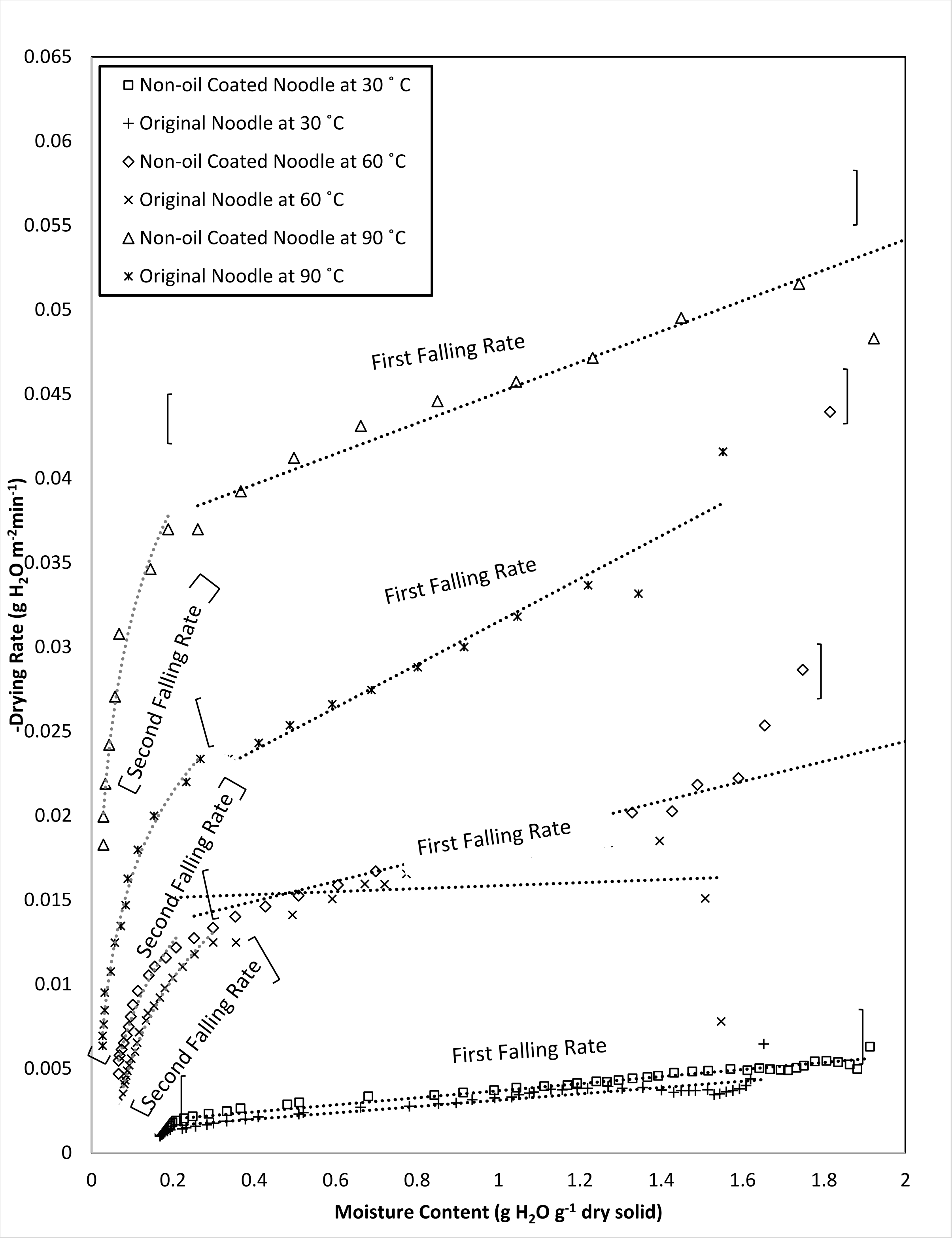


Figure 4.2 Drying rate of hot air drying of rice noodles against moisture content at drying treatment variation

Figure 4.2 shows the drying rate curves of rice noodles at different drying temperature. The hot air drying of rice noodles at the temperature of 30, 60 and

90 °C is described in two falling rate period. Indeed, the drying rates are falling in a steady manner in the initial stage of the drying, before falling rapidly towards equilibrium except at 30 °C (Zhu et al. 2010). In particular, hot air drying at high temperature of 90 °C recorded very high drying rate. Drying at this temperature, the noodle surface heated up and its moisture became promptly vaporized by the circulated hot air before being removed by the surrounding air (Kongkiattisak & Songsermpong 2012). In fact, drying at high temperature took just several hours due to higher drying rates to eventually record the lowest moisture content at its equilibrium (Smith & Jung 1993).

In specific to the drying regime at these temperatures, first falling rate period occurs when wet surface escapes to the atmosphere until it is completely dried. After that, second falling rate period starts whereby the plane of evaporation moves away from the noodle surface as internal diffusion triggers. Indeed, the amount of water being removed which is from the critical moisture content, m_c to the equilibrium is relatively smaller than the first falling rate period. Furthermore the drying period takes longer time because the process is slower than the first falling rate. This is due to the heat required for internal moisture removal is distributed through the noodle to the moisture mitigation within the noodle whereby the vapour moves through the noodle into air stream.

It can be learnt that rice noodle is a thin layer food material whereby it tends to enter falling rate period faster. Rice noodle does not exhibit constant drying rate period, which agreed with many other drying studies of thin layer consumables such as strawberries and onions (Shih et al. 2008; Gabel et al. 2006). Thus, the overall hot air drying process of rice noodle is in the falling rate period. As soon as the sample surface temperature reached its equilibrium, the falling rate period occurred swiftly as the removal of unbound water from the product could not be observed. The amount of water evaporates is not parallel to the amount of water on the surface of product. This has resulted in the moisture diffusion within the noodle strands which created a moisture gradient along the inclination from the core to the surface of the noodle strands (Doymaz 2014).

In the meantime, the hot air drying at 30 °C gradually fall in the falling rate period. The first falling rate period which described the removal of unbound water from the noodle behaves in a very steady manner, to the small amount of g H_2O moisture being removed per minute. At this very low temperature, the amount of water evaporates is consistently equal to the amount of water supplied to the noodle surface, which is merely restricted to the slow air circulation before it falls in second falling rate period towards equilibrium. This is attributed to the gentle temperature that was introduced to the drying system which shows slowly decelerating falling rate leading to the very long duration of the drying process.

In regards to the effects of pre-treatment, the non-oil coated rice noodle showed slightly higher drying rates than the original rice noodle. The non-oil coated rice noodle reached the equilibrium earlier than the original rice noodle, simply because the internal moisture of the noodle strand migrates to the surface to evaporate a little faster than the original rice noodle. This is due to the fact that pre-treatment removed the oil on noodle surface across the noodles which enabled the moisture within the overall noodle slab to escape to the atmosphere. The drying speed of further drying is eventually restricted to the rate of moisture diffusion from the noodle core to the surface layer.

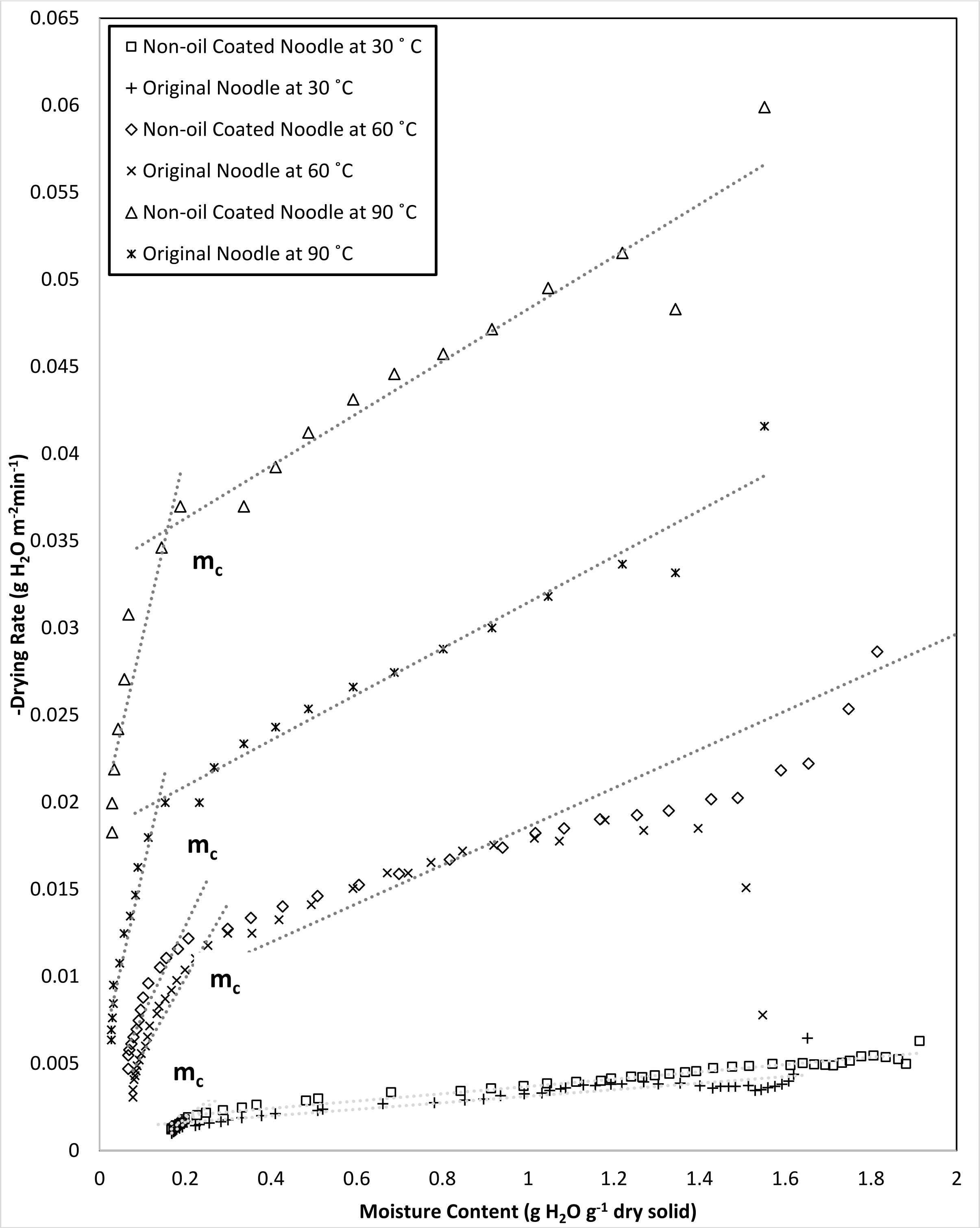


Figure 4.3 The critical moisture content, m_c of rice noodle at hot air drying treatment variation

Figure 4.3 describes the critical moisture content, m_c of rice noodle at drying treatment variation. The critical moisture content was determined by extrapolating two linear trend lines which were represented by two different drying periods until they touch each other denoted by the intersection point. The point was then determined by using SLOPE AND INTERCEPT function in Excel.

It may somehow describes the falling rate period of the internal drying which took longer time to reach equilibrium. In general, critical moisture content is the point that distinguishes two different drying periods. It may also describe internal diffusion in the noodles. After the critical point is reached, the drying rate starts to decrease whereby the surface water activity falls to less than one. At this point, the drying rate is solely governed by the internal flow of moisture and there is not enough water on the surface to maintain a water activity value of one.

With reference to that, the critical moisture content of rice noodle subjected to hot air drying is tabulated as in Table 4.1. By definition, the critical moisture content occurs to describe the changes of drying period. This is the point where heat required for moisture removal is transferred through the solid to the vaporization of moisture in the solid and the vapour moves through the solid into air stream. The m_c at the temperature of 30, 60 and 90 °C defines the point of internal diffusion between two falling rate periods.

As referring to the table, the critical moisture content, m_c of rice noodle subjected to hot air drying at 30 °C is close to the equilibrium moisture content. The original sample recorded m_c of 0.180, as compared to the equilibrium of 0.167. This is the testament that the amount of water removed in this second falling rate period to be relatively very small compared to the first falling rate period.

In the meantime, the critical moisture content for hot air drying at the temperature of 60 °C and 90 °C is significant to the equilibrium moisture content. This is supported by the fact that the falling rate period at these temperatures can be divided into two steps which describes the internal diffusion. A first falling drying rate occurs when wetted spots in the surface acts as a transit zone with moisture diffusion from the core accumulated at this layer before being removed from the noodle surface to the atmosphere. Second falling rate period begins at following critical point as in Table 4.3 when the surface is completely dry.

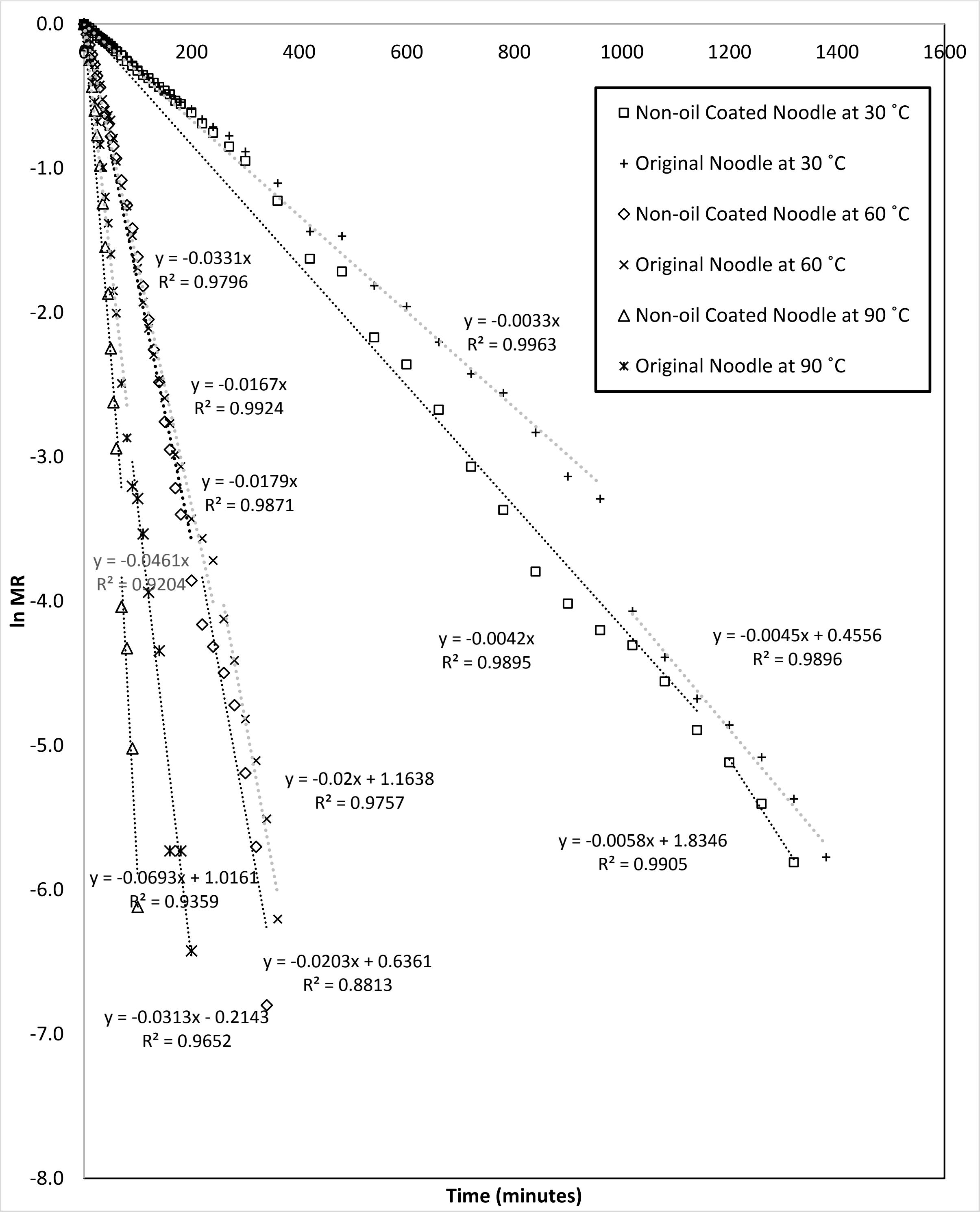


Figure 4.4 ln *MR* of the hot air drying of rice noodles against time at drying treatment variation

In Figure 4.4, the plots of ln (*MR*) against drying time (*t*) give straight lines for the first falling rate of non-oil coated rice noodle of 60 °C and 90 °C with slopes of 0.0179 min^{-1}, and 0.0461 min^{-1}. The respective coefficient of determination (R^2)

from the regression analyses of straight lines is 0.9871, 0.9895 at two temperatures tested.

Meanwhile, the plots of ln (*MR*) against drying time (*t*) give straight lines for the second falling rate of non-oil coated rice noodle of 60 °C and 90 °C with slopes of 0.0203 min^{-1} and 0.0693 min^{-1}. The respective coefficient of determination (R^2) from the regression analyses of straight lines is 0.9648, 0.9905 at two temperatures tested.

In conjunction to that, the plots of ln (*MR*) against drying time (*t*) give straight lines for the first falling rate of original rice noodle of 60 °C and 90 °C with slopes of 0.0167 min^{-1}, 0.0331 min^{-1}. The respective coefficient of determination (R^2) from the regression analyses of straight lines is 0.9924, 0.9963 at two temperatures tested. Meanwhile, the plots of ln (*MR*) against drying time (*t*) give straight lines for the second falling rate of original rice noodle of 60 °C and 90 °C with slopes of 0.02 min^{-1} and 0.0313 min^{-1}. The respective coefficient of determination (R^2) from the regression analyses of straight lines is 0.9757, 0.9896 at two temperatures tested.

Furthermore, the plots of ln (*MR*) against drying time (*t*) give straight lines for the first falling rate of non-oil coated rice noodle and original noodle of 30 °C with slopes of 0.0042 min^{-1}, 0.0033 min^{-1}. The respective coefficient of determination (R^2) from the regression analyses of straight lines is 0.9204, 0.9796. Meanwhile, the plots of ln (*MR*) against drying time (*t*) give straight lines for the second falling rate of original coated noodle and original noodle of 90 °C with slopes of 0.0058 min^{-1}, 0.0045 min^{-1}. The respective coefficient of determination (R^2) from the regression analyses of straight lines is 0.9359, 0.9652.

In the meantime, the effective diffusivities for the hot air drying of rice noodle are listed in Table 4.2. The effective diffusivities resulted for the first falling rate of non-oil coated and original rice noodle at 30 °C are 1.60 x 10^{-11} m^2/s, and 1.25 x 10^{-11} m^2/s, respectively. The effective diffusivities obtained for the second falling rate of the respective non-oil coated and original rice noodle at 30 °C are 2.20 x 10^{-11} m^2/s, and 1.71 x 10^{-11} m^2/s.

The effective diffusivities resulted for the first falling rate of non-oil coated rice noodle at 60 °C and 90 °C are 6.80 x 10^{-11} m^2/s, and 1.75 x 10^{-10} m^2/s respectively. The effective diffusivities obtained for the second falling rate of non-oil coated rice noodle at 60 °C and 90 °C are 7.71 x 10^{-11} m^2/s, and 2.63 x 10^{-10} m^2/s, respectively.

Table 4.2 Effective diffusivity of the hot air drying (HAD) of rice noodle

Drying Treatment	**Falling Rate**	**D_{eff} (m^2/s)**
Non-oil Coated Noodle HAD at 30 °C	First	1.60 x 10^{-11}
	Second	2.20 x 10^{-11}
Original Noodle HAD at 30 °C	First	1.25 x 10^{-11}
	Second	1.71 x 10^{-11}
Non-oil Coated Noodle HAD at 60 °C	First	6.80 x 10^{-11}
	Second	7.71 x 10^{-11}
Original Noodle HAD at 60 °C	First	6.35 x 10^{-11}
	Second	7.59 x 10^{-11}
Non-oil Coated Noodle HAD at 90 °C	First	1.75 x 10^{-10}
	Second	2.63 x 10^{-10}
Original Noodle HAD at 90 °C	First	1.26 x 10^{-10}
	Second	1.18 x 10^{-10}

The effective diffusivities resulted for the first falling rate of original rice noodle at 60 °C and 90 °C are 6.35 x 10^{-11} m^2/s and 1.26 x 10^{-10} m^2/s respectively. The effective diffusivities obtained for the second falling rate of original rice noodle at 60 °C and 90 °C are 7.59 x 10^{-11} m^2/s and 1.18 x 10^{-10} m^2/s respectively. These values fall within the range of noodles reported by other researchers (Kongkiattisak & Songsermpong 2012; Inazu & Iwasaki 2000).

In this study, it was found that higher drying temperature increases the effective diffusivity by increasing the mass and heat transfer (Minaei et al. 2012). Furthermore, non-oil coated noodle recorded higher value of effective diffusivity than the original sample. As illustrated in earlier finding, noodle washing enable the moisture to escape to the atmosphere to facilitate higher effective diffusivity.

In the meantime, the effective diffusivity in second falling rate of hot air drying at 30, 60 °C and 90 °C is generally higher than first falling rate. This indicates that the amount of water removed in this period to be relatively higher than the first falling rate that usually occurs in particular to thin layer materials (Olalusi 2014).

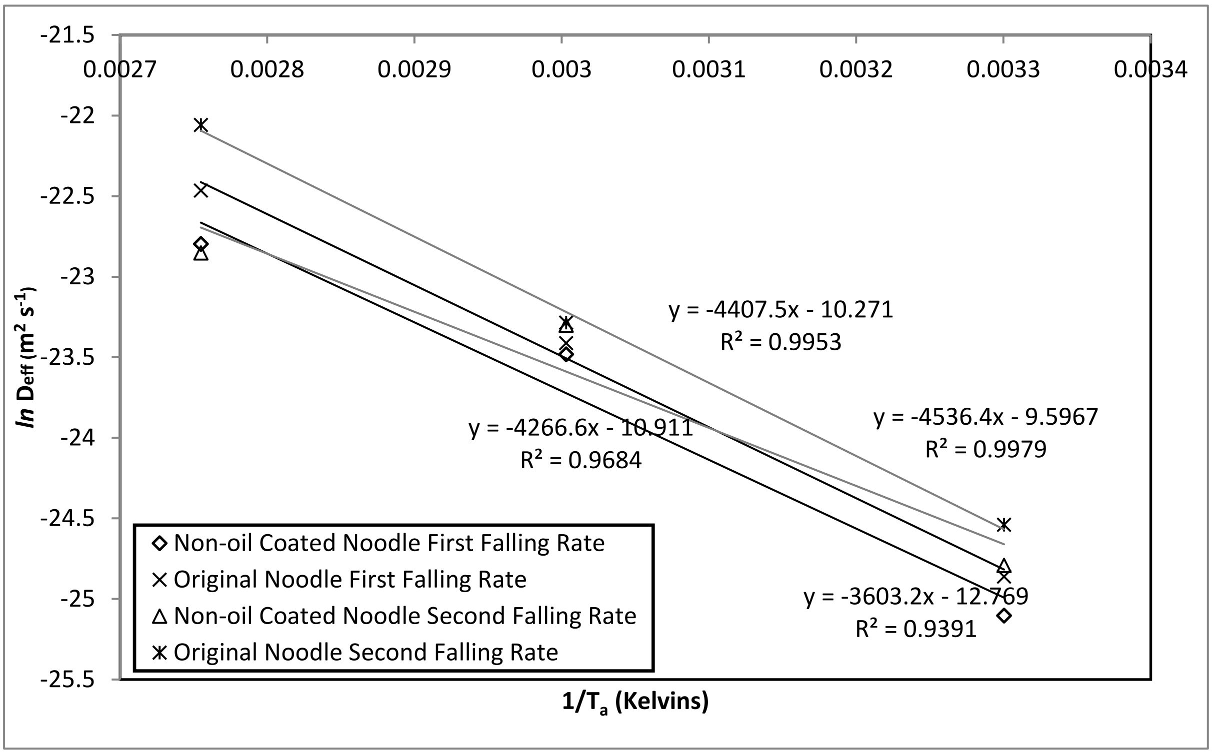


Figure 4.5 The logarithm of effective diffusivity (D_{eff}) against 1/T_a for non-oil coated and original rice noodle

Figure 4.5 shows a linear relationship between the logarithms of effective diffusivity (D_{eff}) as a function of the reciprocity of the absolute temperature (*a*) is plotted. The activation energy (E_a) is determined from the slope and the diffusivity constant (D_o) is determined by y intercept. The list of activation energy (E_a) and diffusivity constant (D_o) of rice noodle is listed as in Table 4.3 below.

Table 4.3 Activation energy (E_a) and diffusivity constant (D_o) of rice noodle

Drying Treatment	**Falling Rate**	**E_a (kJ/mol)**	**D_o**
Non-oil Coated Noodle	First Falling Rate	35.473	1.826 x 10^{-5}
	Second Falling Rate	29.958	2.848 x 10^{-6}
Original Noodle	First Falling Rate	36.645	3.462 x 10^{-5}
	Second Falling Rate	37.717	6.795 x 10^{-5}

The calculated diffusivity constant (D_o) and activation energy (E_a) for non-oil coated noodle are 1.826 x 10^{-5} and 35. 473 kJ/mol in first falling rate period and 2.848 x 10^{-6} and 29.958 kJ/mol in second falling rate period. The calculated diffusivity constant (D_o) and activation energy (E_a) for original noodle are 3.462 x 10^{-5} and 36.645 kJ/mol in first falling rate period and 6.795 x 10^{-5} and 37.717 kJ/mol in second falling rate period.

In this study, the D_o of second falling rate of non-oil coated noodle was higher than D_o of first falling rate to indicate that moisture diffusion occurred largely in the second falling rate period. The D_o of first falling rate of original noodle was higher than D_o of second falling rate to describe that diffusion occurred mainly in the first falling rate period as in agreement to the E_a.

By definition, E_a represents the amount of energy required to remove moisture from the material (Minaei et al. 2012). In this study, the activation energy of non-oil coated sample is lower than original noodle to indicate lower energy used to facilitate higher effective diffusivity in non-oil coated sample than original noodle, as previously mentioned. This is consistent to the previous finding on effective diffusivity that the activation energy of second falling rate of non-oil coated noodle was lower than the first falling rate to indicate lower energy used to promote higher moisture diffusion in second falling rate period. In the meantime, the activation energy of original noodle was not that obvious to conclude that hot air drying of the sample fall in first and second falling rate period.

In this research of plain rice noodle, the activation energy was found to be in the range of 29.958 to 37.717 kJ/mol. In a rice noodle drying study (Kongkiattisak & Songsermpong 2012), the activation energy values are around 17 kJ/mol for the author’s self-made Thai rice noodles and 21.3 kJ/mol for Udon (Inazu 2000). Indeed, the values may differ due to the processing conditions, types of packaging and source of raw materials (Rasouli et al. 2011).

4.2 HEAT PUMP DRYING OF RICE NOODLES

4.2.1 Influence of drying parameter on drying kinetics

The weight of rice noodle subjected to heat pump drying at different drying treatment is measured until the moisture content has reached equilibrium. Table 4.5 shows the drying time required for rice noodle to reach the equilibrium moisture content as is illustrated in Figure 4.4. The rice noodle subjected to heat pump drying at the higher temperature recorded the shortest drying time. Indeed, the noodle layer reaches the equilibrium moisture content much earlier because the layer is instantaneously exposed to the high convective air velocity in heat pump drying. As previously mentioned, drying temperature as well as air velocity hugely influences the drying time of heat pump drying.

At the temperature of 50 °C, non-oil coated rice noodle recorded 240 minutes of total drying duration and original rice noodle took 270 minutes towards equilibrium. At the temperature of 38 °C, the non-oil coated noodle took 720 minutes and original rice noodle took 780 minutes to reach equilibrium. Indeed, higher drying temperature with low humidity of 21.2% eventually speeds up the drying process by increasing the rate of drying.

In the meantime, the effects of pre-treatment prevail for heat pump drying by learning the equilibrium moisture content. The equilibrium moisture contents for heat pump drying at 38 °C were found to be lower for the non-oil coated noodle at 0.063 g H_2O g^{-1} dry solid and 0.101 g H_2O g^{-1} dry solid for the original rice noodle. For the heat pump drying at 50 °C, the equilibrium moisture contents were 0.085 g H_2O g^{-1} dry solid and 0.094 g H_2O g^{-1} dry solid for the respective non-oil coated and original rice noodle.

Indeed, the equilibrium moisture content for the non-oil coated rice noodle subjected to pre-treatment seemed to be slightly lower than the original rice noodle despite higher initial moisture content. Higher initial moisture content is due to the pretreatment that makes the sample to contain more water. Regardless the main objective in introducing pre-treatment to rice noodle is merely to remove the coated oil, it has become the great importance to the drying of rice noodle particularly in reducing the drying time as well as the equilibrium moisture content.

Table 4.4 The time required to reach the equilibrium moisture content with respect to different heat pump drying process parameters.

Temperature (°C)	**Relative Humidity (%)**	**Pre-treatment**	**Drying Time (minutes)**	**Equilibrium Moisture Content (g H_2O g^{-1} dry solid)**	**Critical Moisture Content (g H_2O g^{-1} dry solid)**
38	35.2	Non-oil Coated	720	0.063	0.955
		Original	780	0.101	1.005
50	21.2	Non-oil Coated	240	0.085	0.401
		Original	270	0.094	0.716

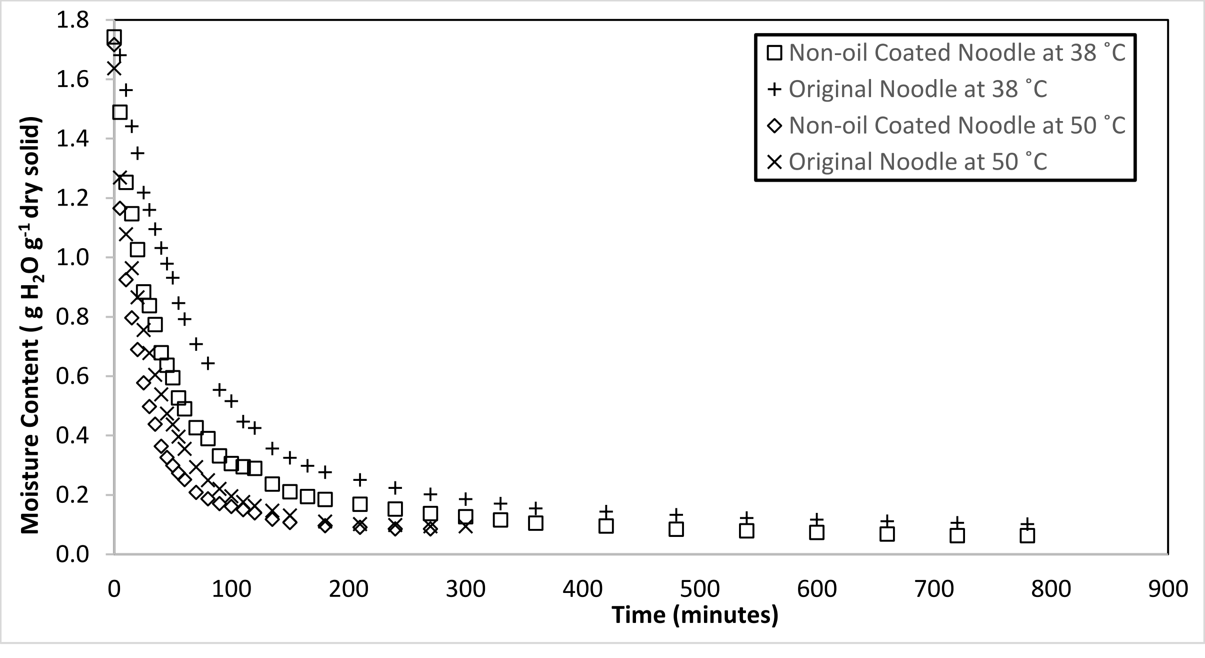


Figure 4.6 Moisture content against time of heat pump drying of rice noodles at drying treatment variation

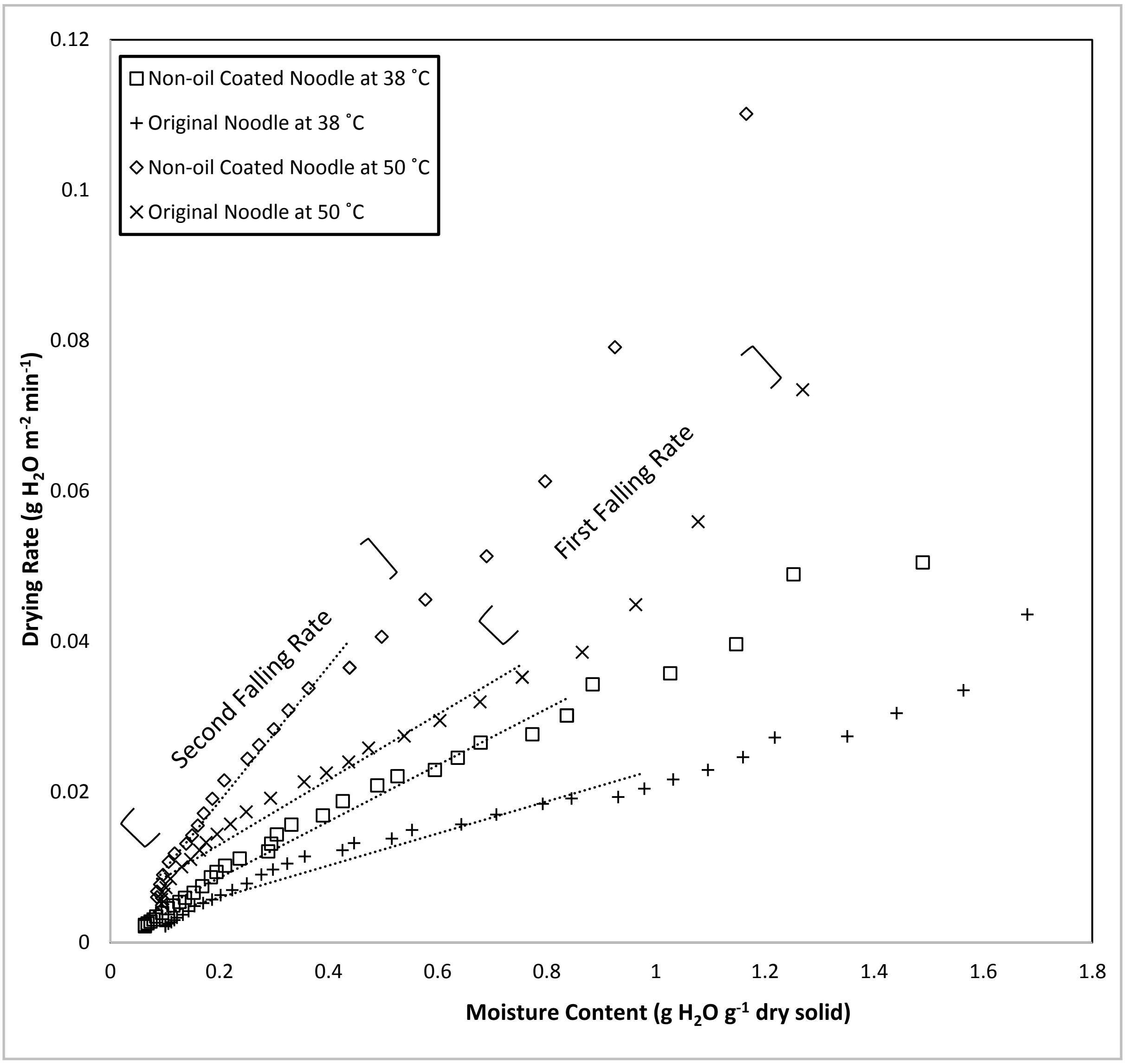


Figure 4.7 Drying rate of heat pump drying of rice noodles against moisture content at drying treatment variation

Figure 4.7 shows the drying rates of rice noodles with and without pre-treatment that were subjected to heat pump drying at two temperatures namely 38 °C and 50 °C. The drying rate of rice noodle as thin layer consumables tends to fall in falling rate period faster with no constant rate period. Therefore, it can be learnt that heat pump drying of rice noodle fall in strictly two falling rate period which is attributed to high air velocity employed in the system.

In regards to heat pump drying, the overall drying rates were found to be higher for the temperature of 50 °C especially in the initial drying stage (0-2h) compared to 38 °C. As shown from the sharp drop of the moisture content, moisture removal from the core in the first falling rate is also faster. Indeed, the superficial surface moisture content at the external noodle layer is contributed to the rapid drop. After the noodle layer starts to harden, the moisture diffusion from the core to the noodle surface in the second falling rate was restrained. Due to the lower water diffusion after surface hardening, only then it restricted the moisture diffusion flow.

In the meantime, the moisture content of non-oil coated rice noodle in the beginning of drying was much higher than the original rice noodle. This is because pre-treatment process makes the sample to contain more water at the initial stage which is easily removed from the noodle surface prior to the surface starting to dry up. Therefore, the overall moisture migration rate of non-oil coated noodle is faster because pre-treatment induces the drying rate of the process.

Indeed, pre-treatment process stretches out the tissue cells so moisture may escape and later penetrates the moisture gradient from the initial moisture content to the equilibrium. It is worth mentioning that at the end of drying, the drying rates of the original rice noodle was actually lower than the non-oil coated rice noodles. This indicates that resistance to mass transfer is mostly contributed by the oil coating on the noodle surface whereby there is a reduced rate of diffusion once the moisture reaches this layer.

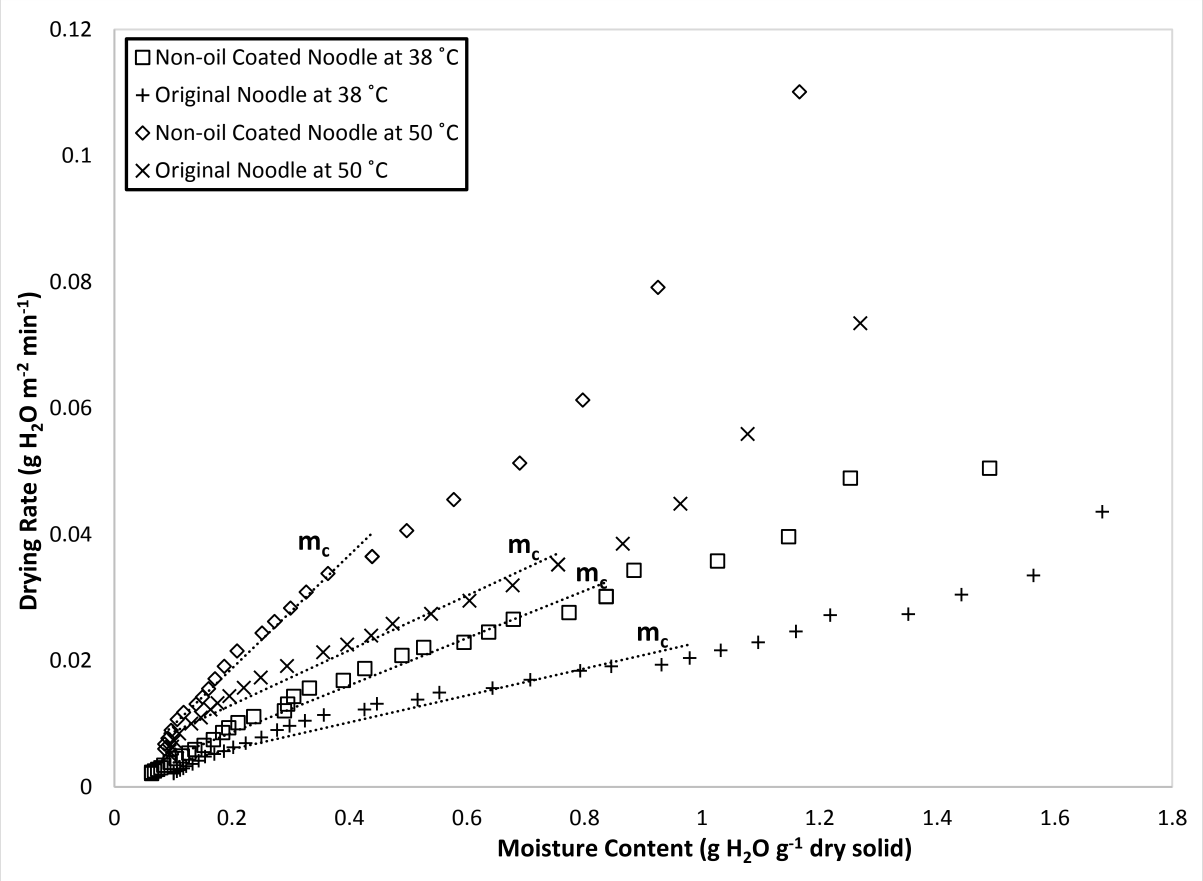


Figure 4.8 The critical moisture content, m_c of rice noodle at heat pump drying treatment variation

Figure 4.8 shows the plot of critical moisture content, m_c of rice noodle at heat pump drying treatment. The list of critical moisture content can be found in Table 4.5. The m_c of non-oil coated and original rice noodle subjected to heat pump drying at 38 °C was respectively at 0.955 and 1.005 g H_2O g^{-1} dry solid. The equilibrium moisture content, m_e of non-oil coated and original rice noodle subjected to heat pump drying at 38 °C was respectively at 0.063 and 0.101 g H_2O g^{-1} dry solid.

In the meantime, the m_c of non-oil coated and original rice noodle subjected to heat pump drying at 50 °C was respectively at 0.401 and 0.716 g H_2O g^{-1} dry solid. The equilibrium moisture content, m_e of non-oil coated and original rice noodle subjected to heat pump drying at 50 °C was respectively at 0.085 and 0.094 g H_2O g^{-1} dry solid.

From the list, it can be learnt that the overall drying rates of rice noodle subjected to heat pump drying are fast by observing the difference between m_c and m_e in comparison to the hot air drying at 30 °C. Pre-treatment of rice noodle in heat pump drying recorded slightly lower values of m_c which is in parallel to the lower values of m_e to indicate faster drying rates in the non-oil coated sample than the original noodle.

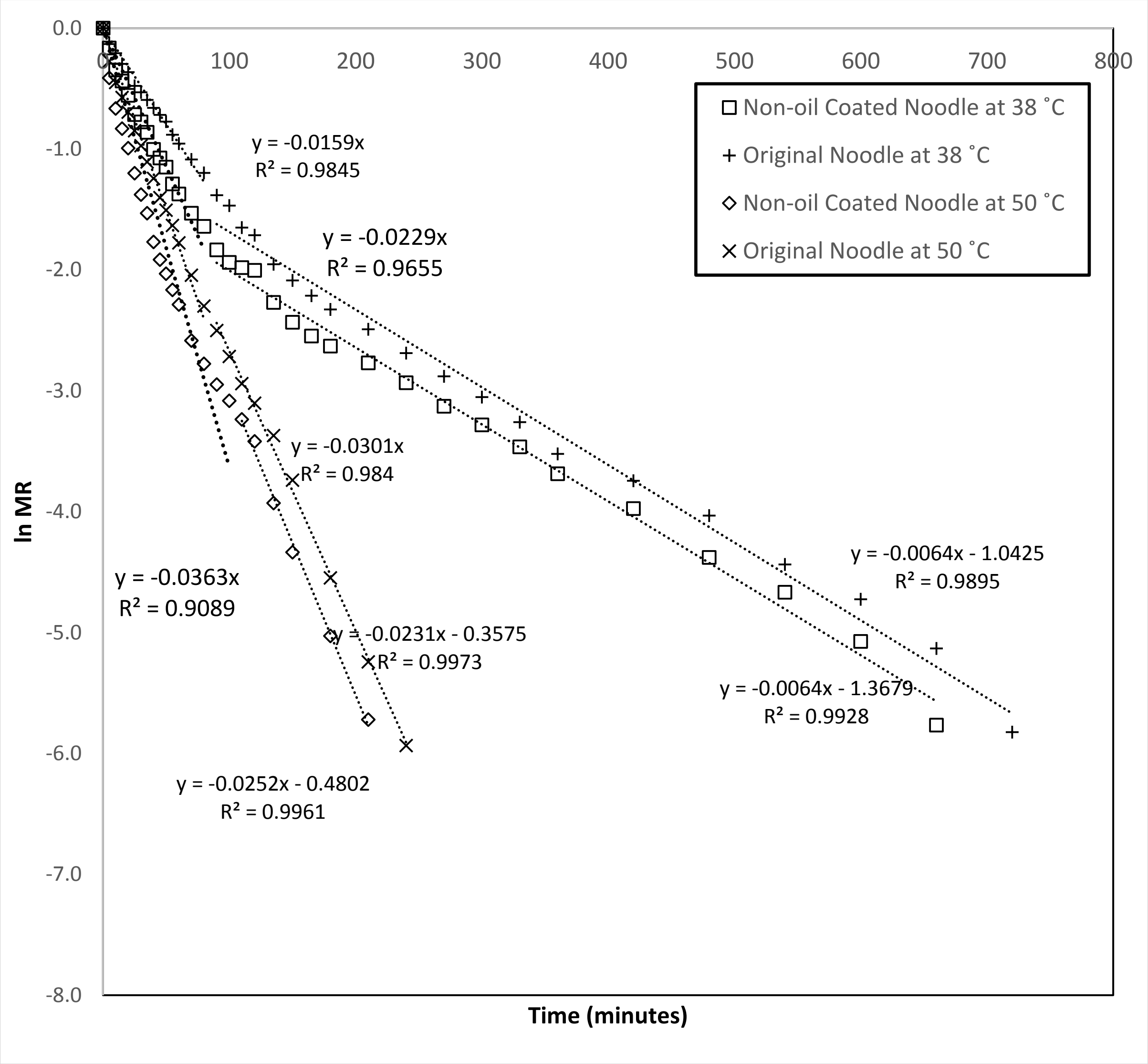


Figure 4.9 ln MR of the heat pump drying of rice noodles against time at drying treatment variation

In Figure 4.9, the plots of first falling rate period of ln (MR) against drying time (t) at 38 °C give straight lines for the respective non-oil coated and original noodle with slopes of 0.0204 min^{-1}, and 0.0147 min^{-1}. The respective coefficient of determination (R^2) from the regression analyses of straight lines is 0.9655, and 0.9845 at the temperatures tested. The effective diffusivities obtained for the sample mentioned are 7.75 x 10^{-11} m^2/s, and 5.59 x 10^{-11} m^2/s respectively and simplified as in Table 4.5.

Table 4.5 Effective diffusivity of the heat pump drying (HPD) of rice noodle

Drying Treatment	**Falling Rate**	**D_{eff} (m^2/s)**
Non-oil Coated Noodle HPD at 38 °C	First	7.75 x 10^{-11}
	Second	2.43 x 10^{-11}
Original Noodle HPD at 38 °C	First	5.59 x 10^{-11}
	Second	2.43 x 10^{-11}
Non-oil Coated Noodle HPD at 50 °C	First	1.14 x 10^{-10}
	Second	9.58 x 10^{-11}
Original Noodle HPD at 50 °C	First	1.05 x 10^{-10}
	Second	8.78 x 10^{-11}

Meanwhile, plots of ln (*MR*) versus drying time (*t*) for the second falling rate at 38 °C give straight lines for the non-oil coated and original rice noodle with slopes of 0.0064 min^{-1}, and 0.0064min^{-1}. The respective coefficient of determination (R^2) from the regression analyses of straight lines is 0.9928, and 0.9895 at the temperatures tested. The effective diffusivities obtained for the mentioned samples at 38 °C were respectively at 2.431 x 10^{-11} m^2/s.

Furthermore, the plots of first falling rate period of ln (*MR*) against drying time (*t*) at 50 °C give straight lines for the respective non-oil coated and original noodle with slopes of 0.03 min^{-1}, and 0.0275 min^{-1}. The respective coefficient of determination (R^2) from the regression analyses of straight lines is 0.9089, and 0.984 at the temperatures tested. The effective diffusivities obtained for the sample mentioned are 1.14 x 10^{-10} m^2/s, and 1.05 x 10^{-10} m^2/s respectively.

The plots of ln (*MR*) versus drying time (*t*) for the second falling rate at 50 °C give straight lines for the non-oil coated and original rice noodle with slopes of 0.0252 min^{-1}, and 0.0231 min^{-1}. The respective coefficient of determination (R^2) from the regression analyses of straight lines is 0.9961, and 0.9973 at the temperatures tested. The effective diffusivities obtained for the mentioned samples at 50 °C were respectively at 9.575 x 10^{-11} m^2/s and 8.78x 10^{-11} m^2/s.

The effective diffusivities for non-oil coated sample were higher than the original rice noodle at 38 °C, and 50 °C. The amount of water removed in this pre-treatment to be relatively higher which is denoted by faster drying duration in non-oil coated sample than the original sample. This is due to the higher rate of diffusion through porous media in non-oil coated sample than the original noodle since the effects of pre-treatment enable water to escape to the atmosphere faster. Therefore, the pre-treatment of rice noodle subjected to hot air drying and heat pump drying specifically exhibited higher effective diffusivity than the original noodle.

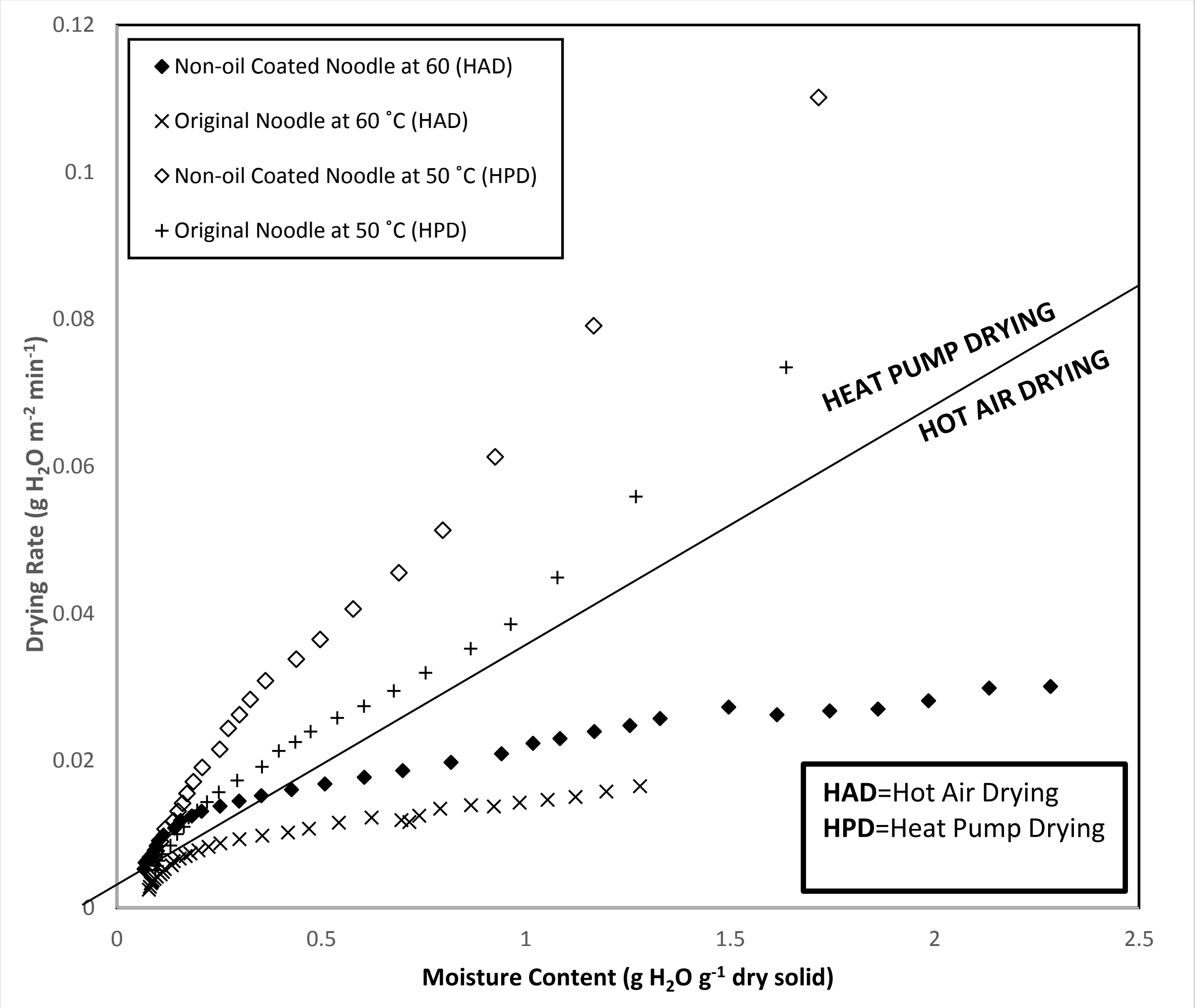


Figure 4.10 The drying rate versus moisture content of the hot air drying and heat pump drying of rice noodle.

Figure 4.10 shows the drying rate versus moisture content of hot air drying and heat pump drying of rice noodle. It is a combination of Figure 4.3 and Figure 4.7 for the purpose of comparison of drying rate for these two drying techniques. The drying performance of rice noodle was investigated by performing hot air drying at the temperature of 60 °C and heat pump drying at 50 °C. Drying temperature of 60°C was selected as it is commonly used in the drying of rice noodles in the industry. The drying medium in heat pump drying was prepared at the temperature that was lower than hot air drying but at relative humidity that is parallel to hot air drying.

All the drying rate curves of both original and non-oil coated rice noodles subjected to heat pump drying were faster as heat pump drying was more excessive than hot air drying. The higher drying rates were due to the rapid drop of the surface moisture content. This is due to the fact that the rice noodles was partially dry at the beginning of the drying process whereby the water activity was smaller than 1.0. The initial drying rates of HPD at 50 °C was in the range of 0.10 g H_2O m^{-2} min^{-1} to 0.05 g H_2O m^{-2} min^{-1} which was higher than the highest drying rate of HAD at 60 °C in the range of 0.03 to 0.04 g H_2O m^{-2} min^{-1}. This is due to higher air velocity which enabled free bound moisture on the surface to escape to the atmosphere.

Therefore, the drying rate of rice noodle subjected to hot air and heat pump drying was hugely influenced by air velocity. Higher air velocity employed in heat pump drying system at 4.6 ms^{-1} ± 0.5 triggered the moisture inclination from the core along the noodle surface in comparison to the velocity in hot air drying at 1.401 ms^{-1} ± 0.5 which can be learnt clearly from the dictated curves.

The drying rate of hot air drying was found to be lower than the heat pump drying. This is due to the fact that air relative humidity HPD (21.2%) is lower than HA (23.3%). Lower air RH translates to a lower water vapour pressure in the drying chamber. The decreased total water pressure in the drying air would induce a higher driving force for the moisture to escape from the solid surface to eventually increase the drying rate.

4.3 QUALITY ATTRIBUTES

Upon dehydration, the sample were then analysed in terms of texture, colour, fat content, starch gelatinization, microstructures, and sensory evaluation. The high quality of noodle should be bright in colour, adequate shelf life without rancidity and spoilage and good textural and cooking properties (Ahmed et al. 2016). In the meantime, freeze dried samples were prescribed as the control parameter.

4.3.1 Texture

The results of textural analysis of rice noodle subjected to heat pump drying, hot air drying and freeze drying are presented in this section. The textural analysis is defined by the value of hardness. By right, hardness value defines the level of brittleness of the dried noodle strand to break subjected to a particular extent of force. Higher hardness value describes higher stability of the texture, at the point the sample breaks (Ritthiruangdej et al. 2011b).

From Figure 4.11, the hardness values of rice noodle subjected to different drying methods were presented. Rice noodle subjected to hot air drying at 30 °C recorded the hardness value of 2997.6 ± 491.1 g for non-oil coated sample and 2591.6 ± 529.8 g for original sample. Meanwhile, rice noodle under hot air drying at 60 °C recorded 2043.9 ± 543.8 g for non-oil coated sample and 1501.1 ± 272.1 g for original sample. In the meantime, hot air dried rice noodle at 90 °C gave the hardness value of 482.5 ± 111.3 g for non-oil coated sample and 409.6 ± 63.9 g for original sample.

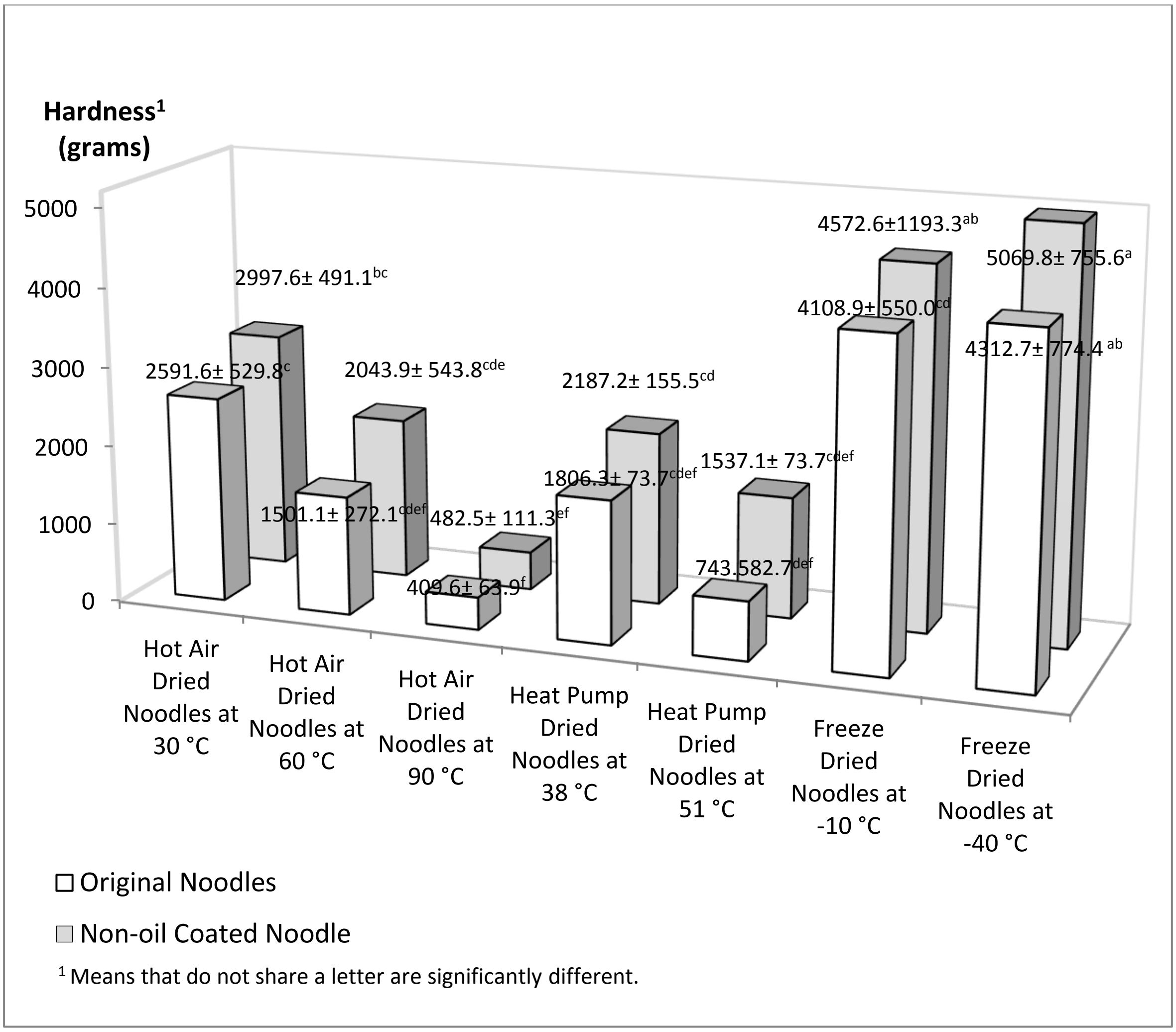


Figure 4.11 Hardness test of rice noodle at drying variation

Thus, higher hardness value recorded by noodle subjected to hot air drying at low temperature indicates harder texture as it registers the high amount of force to break. On the contrary, rice noodle undergoing hot air drying at higher temperature recorded lower hardness value which dictates lower amount of force that is required to break the noodle. Clearly, the excessive hot air which triggers drying duration to be short can overly dehydrate the solid surface, so that its pores shrink and almost close, resulting to noodle decline. Indeed, the compressed noodle surface is due to the drying speed of the noodle core which occurred simultaneously to the external surface. With reference to product quality, it is thus preferably to limit the drying air temperature within an acceptable range in order to avoid excessive shrinkage with poor texture (Inazu et al. 2005).

In fact, excessive drying condition often results in brittle finished product with low hardness value. Higher drying temperature lowered the activity of gel formation to cause weaker gel structure (Chen et al. 2002). Indeed, such low hardness value of hot air drying at 90 °C in dried rice noodle was due to the low content of starch gel to maintain the surface wall. This is supported by the fact that excessive drying condition at high temperature causes surface decline which is susceptible to crack.

On the other hand, heat pump drying of non-oil coated rice noodle under 38 °C recorded the hardness value of 2187.2 ± 155.5 g and the original noodle at 1806.3 ± 230.0 g. At the temperature of 50 °C, heat pump drying of rice noodle recorded the hardness value of 1537.1 ± 73.7 g for non-oil coated noodle and the original noodle at 743.5 ± 82.7 g. Heat pump drying of rice noodle recorded relatively lower hardness value at similar temperature due to the gentle drying. The circulating heat pump loop kept the temperature low by condensing air to facilitate faster drying.

In comparison to hot air drying at equivalent temperature, heat pump drying of rice noodle recorded lower hardness value. This is due to the higher air velocity employed in heat pump drying which gives relatively lower hardness value. In regards to that, the hardness value recorded by hot air drying at 60 °C is higher than the textural behaviour of rice noodle subjected to heat pump drying at 50 °C. This is due to the fact that rapid removal of water on the surface causing noodle surface declines. The internal moisture was released immediately to the atmosphere thus giving simultaneous high stress to the dried surface to cause decline to occur. As a result the surface of the dried noodle is very brittle and prone to crack (Li et al. 2016).

This can conclude that rice noodle subjected to hot air and heat pump drying showed similar trends that higher temperature during drying gives lower hardness value. Lower hardness value indicates texture that is brittle, easy to crack and breaks into pieces and higher hardness value indicates the vice versa, which is preferable for rice noodle processing especially for the purpose of storage.

Finally, the non-oil coated noodle subjected to freeze drying recorded high force of 4572.6 ± 1193.3 g at -10 °C and 5069.8 ± 755.6 g at -40 °C as well as the force of original noodle at 4108.9 ± 550.0 g at -10 °C and 4312.7 ± 774.4 g at -40 °C to break the noodle sample. The sub-zero temperature environment as well as long desorption procedure in freeze drying has produced large internal pores. Indeed, such slow and gentle drying approach gives a uniform drying to create intact texture (Huang et al. 2011). In addition to that, the formation of more open microstructures leads to high porosity which results to the high stability of noodle texture.

From the results, it can be concluded that the texture of freeze dried noodle at both temperatures was significantly higher ($p < 0.05$) than other drying parameter. In specific, it produces noodle of high stability with higher hardness value. Such high hardness value was attributed to the freezing step in freeze drying which however promotes noodle aging by the reduced air pocket in noodle before subjected to freeze drying (Impaprasert et al. 2016). Freeze drying could produce rice noodle that is stable whereby it is hard to break. In fact, the desirable noodle strands should be strong and straight, with particularly no cracking, not brittle and splitting (Hou 2010).

Furthermore, most findings reported in the literature are based on cooked noodle textural analysis. The cooked noodle value of chewiness, springiness, adhesiveness, and hardness were measured by a HDP/PFS probe. The tensile strength (maximum force; g) and breaking length (distance at maximum force; mm) of the cooked noodle is determined by the noodle made from unripe banana flour (Ritthiruangdej et al. 2011b). Gel hardness was considered to be a dominant factor for texture of cooked noodle (Bhattacharya et al., 1999; Yoenyongbuddhagal & Noomhorm, 2002).

This study focused on the textural analysis of dehydrated noodle. This is due to the need to study the characteristics of the dehydrated noodle, whether the dehydrated noodle are fragile. This is especially important in subject to the packaging of the noodle. In this regard, hardness is the textural attribute that is used in analysing the fragility of the dehydrated noodle. Textural analysis of the cooked noodle is not covered in this study because the sensory evaluation which will be presented in a later section in 4.3.7 revealed that the textural attribute is not significant regardless of the treatment method or drying method.

As a conclusion, gentle drying condition during the drying process of rice noodle is preferred in order to produce a stable texture and less brittle final product. Hardness value is attributed to lower amylose content of rice starch which caused less retrogradation of the starch during gel formation and consequently weaker gel structure. The gel firmness is primarily due to the retrogradation of starch gels, which is incorporated with the syneresis of water and crystallization of amylopectin, resulting to harder gels (Miles et al, 1985). A hardness value should be sufficiently high to avoid the dehydrated rice noodle from breaking into pieces. The hardness value of higher than 700 g is deemed to be satisfactory for any packaging methods (Rachtanaput et al. 2011). A higher hardness value recorded by freeze drying is in response to the higher scores of textural attributes in the sensory evaluation which will be discussed later in 4.3.7.

4.3.2 Colour

The physical appearance of a specific product has been the main preference of Asian customers particularly colour and texture characteristics with no undesirable specks (Hatcher & Anderson 2007). The original and non-oil coated rice noodle tested at different drying conditions was subjected to colour analysis by using CIE Lab colour space. High quality of dried noodle must be bright colour, of smooth and clean surface (Hou 2010). In order to preserve the colour of dried noodle as closest to the fresh noodle, the total colour change was the main parameter in determining the colour change of dried noodle in this study.

Table 4.6 lists the total colour change of all dried samples. Hot air drying at 30°C gave total colour change for non-oil coated noodle of 28.37 ± 3.092 and for original noodle of 35.100 ± 2.307. Hot air drying at 60 °C recorded total colour change of 35.900 ± 5.242 for non-oil coated noodle and 36.767 ± 5.918 for original noodle. Finally, the total colour change was apparent at 43.033 ± 2.307 for non-oil coated noodle and 43.867 ± 1.498 for original noodle at 90 °C.

The increment of drying temperature increases the respective total colour change. In specific, as the temperature increases, it leads to obvious colour changes due to strong heating effect. Higher drying temperature tends to cause discolouration such as browning effects to the products. Moreover, the discoloration at 30 °C is due to the enzyme activation at warm temperatures which also causes foreign odour formation, particularly when the main drying is very long (Gary G. Hou 2010). As a results, the noodle was dried to browning which causes a very high colour change to eventually make it least favourable (Kim et al. 1988).

Table 4.6 Colour parameters of rice noodle at drying variation

Treatment			**Total Colour Change, ΔE***
Hot Air Drying	30 °C	Non-oil Coated	28.367± 3.092^{cd}
		Original	35.100 ± 2.307^{bc}
	60 °C	Non-oil Coated	35.900± 5.242^{abc}
		Original	36.767± 5.918^{abc}
	90 °C	Non-oil Coated	43.033± 2.307^{ab}
		Original	43.867± 1.498^{ab}
HPD	38 °C	Non-oil Coated	41.233± 4.302^{ab}
		Original	42.267± 4.912^{ab}
	50 °C	Non-oil Coated	43.000± 2.821^{ab}
		Original	45.667± 3.500^{a}
Freeze Drying	-10 °C	Non-oil Coated	23.033± 1.290^{de}
		Original	18.033± 3.099^{e}
	-40 °C	Non-oil Coated	19.333± 1.124^{de}
		Original	18.400± 1.473^{de}

[1] Means that do not share a letter are significantly different.

Colour changes of non-oil coated and original samples obtained from heat pump drying at 38 °C and 50°C are obvious. The colour changes of non-oil coated noodle and original noodle at 38 °C were recorded at 41.233 ± 4.302 and 42.267 ± 4.912 respectively. Meanwhile, colour changes of non-oil coated noodle and original noodle undergoing heat pump drying at 50 °C are 43.000 ± 2.821 and 45.667 ± 3.500. The total colour change in heat pump drying of rice noodle is higher due to the higher air velocity which caused disruption to the colour of the fresh sample.

Similar to the trends in hot air drying, as the temperature of heat pump drying increases, the colour changes are getting more distinct (Hu et al. 2006). The heat pump drying at higher air velocity also cause significant colour change to the noodle to eventually degrade the overall food colour quality. Higher air velocity tends to further trigger oxidative reactions and enzymatic browning to cause the brown stain of the dried products due to the Maillard reaction (Zhu et al. 2010). The Maillard reaction is activated at sufficient heat between amino acids and reducing sugars (starch) in the noodle to cause non-enzymatic browning reaction (Martins et al. 2000).

In the meantime, pre-treatment process produces a relatively high intensity and saturation inside the rice noodle. The pre-treatment tends to remove all the initial impurities especially oil from the sample hence dehydrated non-oil coated samples tend to get a brighter colour which leads to lower colour change for most noodle samples at different drying treatments (Nour et al. 2011).

Furthermore, the colour changes of freeze dried non-oil coated and original rice noodle at the temperatures of -10 °C and -40 °C was significantly lower ($p< 0.05$) than hot air and heat pump drying. A total colour change for non-oil coated noodle undergoing freeze drying was observed at 23.033 ± 1.290 at -10°C and 19.333 ± 1.124 at -40 °C compared to the original noodle at 18.033 ± 3.099 at -10°C and 18.400 ± 1.473 at -40 °C.

Freeze drying gives a higher value of colour change in non-oil coated rice noodle due to pre-treatment which induces more ice deposit prior to freezing step to which caused the change. Pei, F. (2014.) reported that more ice deposit to be observed prior to freeze drying which has eventually disturbed the colour change of the dried sample. This slight colour change is further enhanced by the slow and gentle desorption process in freeze drying.

Low temperature does not induce browning effect to the noodle to preserve the white colour closest to the fresh noodle, as reported by previous studies (Savo et al. 2012; Henriques et al. 2012). Zieliñska et al. (2005) suggested that the colour of cooked noodle in the sensory analysis confirms the total colour change of dried noodle by instrumental measurement which will be presented in 4.3.7.

4.3.3 Starch Gelatinization

In the evaluation of instant and dry noodle, short cooking time has always been the main priority (Hou & Kruk 1998). Prior to cooking, the starch in rice noodle is gelatinized with the presence of water and heat. Starch gelatinization is an endothermic reaction describing the dissociation of intermolecular bonds of starch molecules. This is to allow hydrogen bonding sites to engage more water. The heat transported through the aqueous medium in gelatinization, and the range of gelatinization temperatures is observed by the differential scanning calorimetry (DSC). This irreversible gelatinization process dissolves the starch granule in water (Sakiyan et al. 2011).

In the study, the DSC thermograms of dried rice noodle were obtained and illustrated in the following figures for hot air drying, heat pump drying and freeze drying respectively. Consistent shapes of different endotherms by the rice noodle correspond very closely to the endotherm of corn, potato, pasta, and native rice (Biliaderis et al. 1980; Zhang et al. 2011; Sichina 1992; Heussen et al. 2011). A single endothermic transition was exhibited by all rice noodle variance when heated under minimal water contents.

The gelatinization temperature of rice noodle dried using different methods is summarized in Table 4.8. There are three temperatures correlated with the gelatinization process at which gelatinization began (T_o), a peak temperature (T_p) and that at which gelatinization ceased (T_c) were described through the figures below.

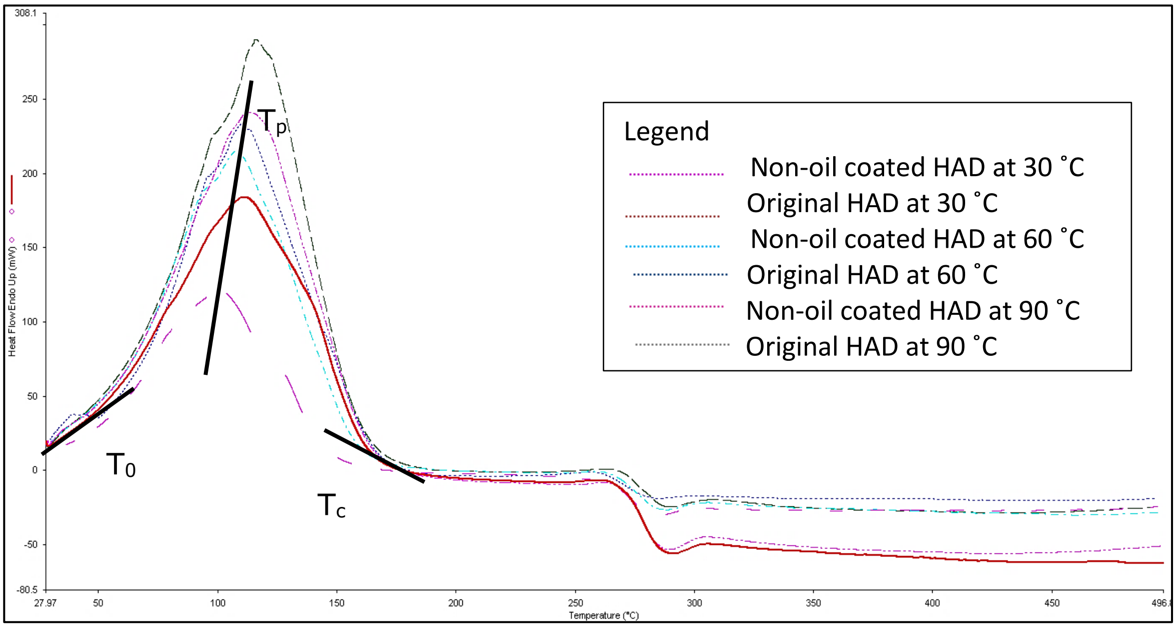


Figure 4.12 DSC results on the gelatinization of the hot air drying of rice noodle

Figure 4.12 shows the DSC results of the hot air drying of rice noodle. The noodle sample produces a well-defined endothermic peak ranging from 101.25 °C until 115.91 °C which reflects the overall gelatinization event. The endothermic peak indicates the melting of the starch. The onset of the transition occurs at the inflection point of 52.55 °C and a high temperature peak is retrieved at 158.86 °C. Since the noodle sample projected normal biphasic endothermic transition it is suggested that this peak might reflect the swelling effects during the gelatinization of such noodle.

The results show indefinite differences between the samples. This is due to the physico-chemical nature of these samples which is purely dependent on the food source. The hydrogen bond arrangement of amylopectin and amylose makes it difficult for water to penetrate into intact starch granules. When the water is heated the granules swell and gelatinization is observed. DSC measures the temperature at which irreversible changes occur in the granule.

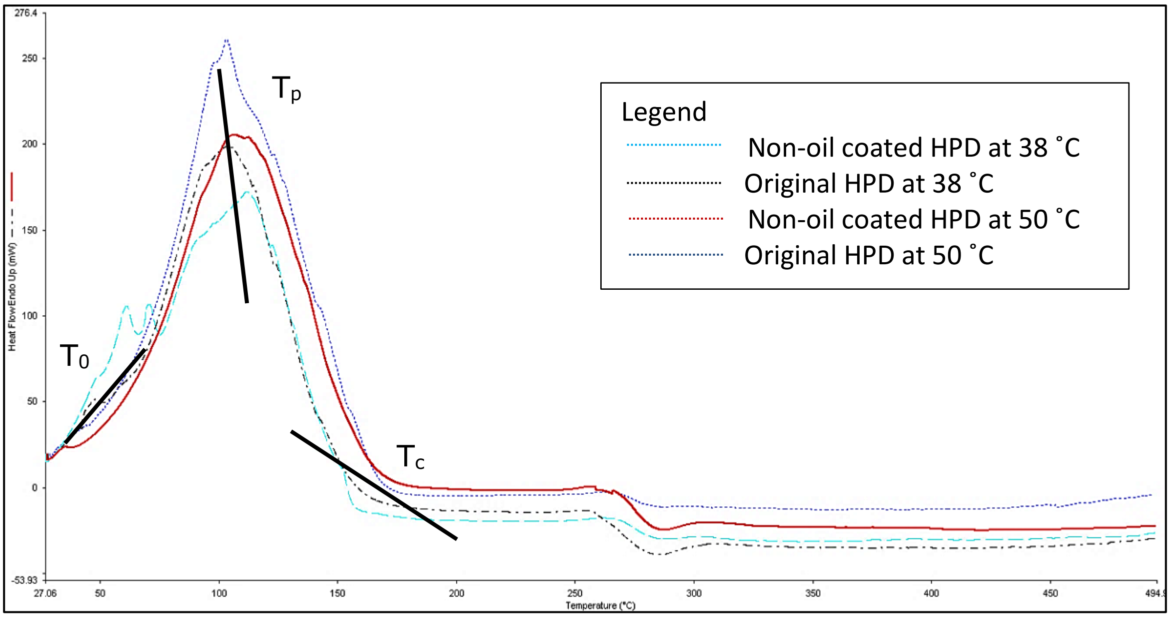


Figure 4.13 DSC results on the gelatinization of the heat pump drying of rice noodle

In dried noodle sample of heat pump drying, the endotherm of starch as in Figure 4.13 showed the tracing of gelatinization at between 35 °C and 154 °C, having an onset at 42°C. The plot of difference expressed as *ΔH*, against temperature showed a drastically decreased enthalpy difference at the temperature between 103 and 154 °C.

The role of water is vital in the overall process by assisting the melting of the starch crystallites. The starch behaviour in excess of water decreased compared to that of water only. According to the theory of polymer solution, the starch immediately dissolves once the free energy becomes theoretically negative (Yamakawa 2001). As the temperature was within the range of gelatinizing temperatures, the starch polymer may have dissolved during gelatinization (Biliaderis et al. 1980).

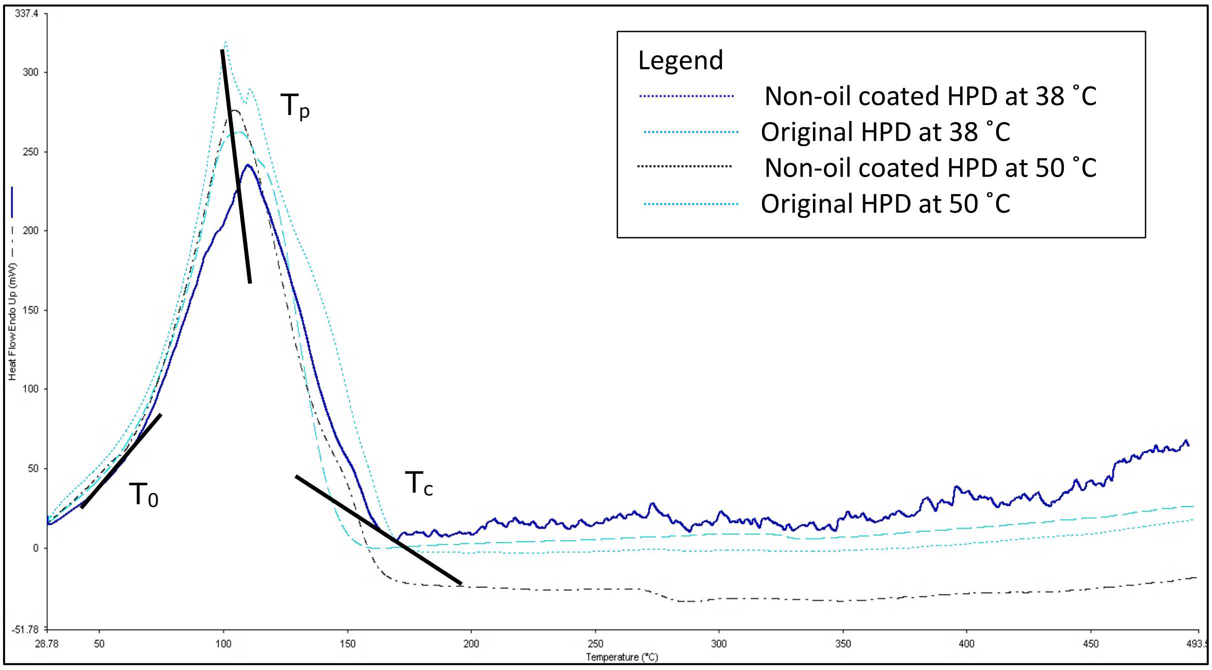


Figure 4.14 DSC results on the gelatinization of the freeze drying of rice noodle

The DSC curves for the freeze drying of rice noodle were determined as in Figure 4.14. Endothermic peaks were observed for all noodle in a temperature range of 29 °C to 142 °C, and the onset, peak, and gelatinization temperatures of each type of noodle were estimated. As the figure shows, the inflection-point temperatures were exactly between the onset and peak temperatures (Hasegawa et al. 2012)

Table 4.7 The gelatinization temperature of rice noodle

Treatment			**T_o (˚C)**	**T_p (˚C)**	**T_c (˚C)**
Hot Air Drying	30 °C	Non-oil Coated	52.55^{a}	111.74^{a}	153.86^{ab}
		Original	53.59^{a}	110.50^{a}	154.69^{ab}
	60 °C	Non-oil Coated	57.52^{a}	115.91^{a}	156.45^{abcd}
		Original	59.42^{a}	118.50^{abc}	156.98^{abcd}
	90 °C	Non-oil Coated	61.10^{abcd}	114.67^{a}	158.10^{abcd}
		Original	63.90^{abcd}	111.37^{a}	158.22^{abcd}
Heat Pump Drying	38 °C	Non-oil Coated	35.76^{ab}	116.59^{abc}	150.43^{a}
		Original	39.27^{ab}	113.26^{a}	150.64^{a}
	50 °C	Non-oil Coated	46.17^{b}	111.73^{a}	154.53^{ab}
		Original	49.23^{b}	116.5^{a}	154.70^{ab}
Freeze Drying	-10 °C	Non-oil Coated	29.04^{ab}	109.84^{ab}	141.07^{abc}
		Original	34.21^{ab}	100.65^{ab}	142.24^{abc}
	-40 °C	Non-oil Coated	33.42^{ab}	106.71^{ab}	141.76^{abc}
		Original	34.41^{ab}	105.04^{ab}	142.71^{abc}

Table 4.7 lists the gelatinization temperature of rice noodle at different drying conditions. Generally, freeze drying of rice noodle significantly lowered ($p < 0.05$) the gelatinization temperature of rice noodle sample. This is attributed to the process itself that preserved the structural changes to the sample so that it may gelatinize faster (Liu et al. 2014). The disruption of crystalline arrangement (long-range ordered structures) or the reduction in the amount of double helices (short-range ordered structures) occurred during the freeze drying process. Therefore, the temperature of the food have to constantly maintain below its *collapse* temperature to keep the ice crystals from melting to sub-gelatinize but sublime at the right operating condition which will be explained in Section 4.5 (Rahman & Durance 2002).

Other drying methods recorded higher gelatinization temperatures which suggest slower structural changes to the food product subjected to gelatinization than freeze drying. Indeed, rice noodle subjected to different drying treatments fully gelatinizes at the temperature higher than 100 °C with freeze dried noodle recorded lowest peak gelatinization temperature, T_p. In fact, starch does not begin to fully gelatinize until it reaches 84 °C (Wu et al. 1998). Therefore the actual gelatinization temperature of noodle should be higher than 84 °C which is in parallel to this study (Hou 2010).

Therefore, this confirms that lower starch gelatinization temperature suggests faster total rehydration ratio recorded by freeze dried samples to the other drying treatments which will be explained further in 4.3.4 (Puspitowati & Driscoll 2007). In regards to that, Baik & Lee (2003) reported that the elastic and soft texture of Japanese white salted noodle or Udon, corresponds to its amylose content and gelatinization temperature which will be explained in Section 4.3.7.

4.3.4 Rehydration Ratio

The most important quality attributes of instant and dried noodle are texture, colour, flavour, and cooking quality as well as rehydration rates on cooking preparation (Gulia et al. 2014). For instant noodle industry, high dehydration ratio is desirable. When dried rice noodle is soaked in hot water, the water migrates from the noodle surface toward the center, to restructure the noodle strand. Therefore, the rehydrated noodle becomes softer. In the early stage of rehydration, the rice noodle absorbs less water and is pretty hard. At the latter stage of rehydration, the rice noodle further absorbs relatively more water and shows a softer texture with lower starch gelatinization (Impaprasert et al. 2016).

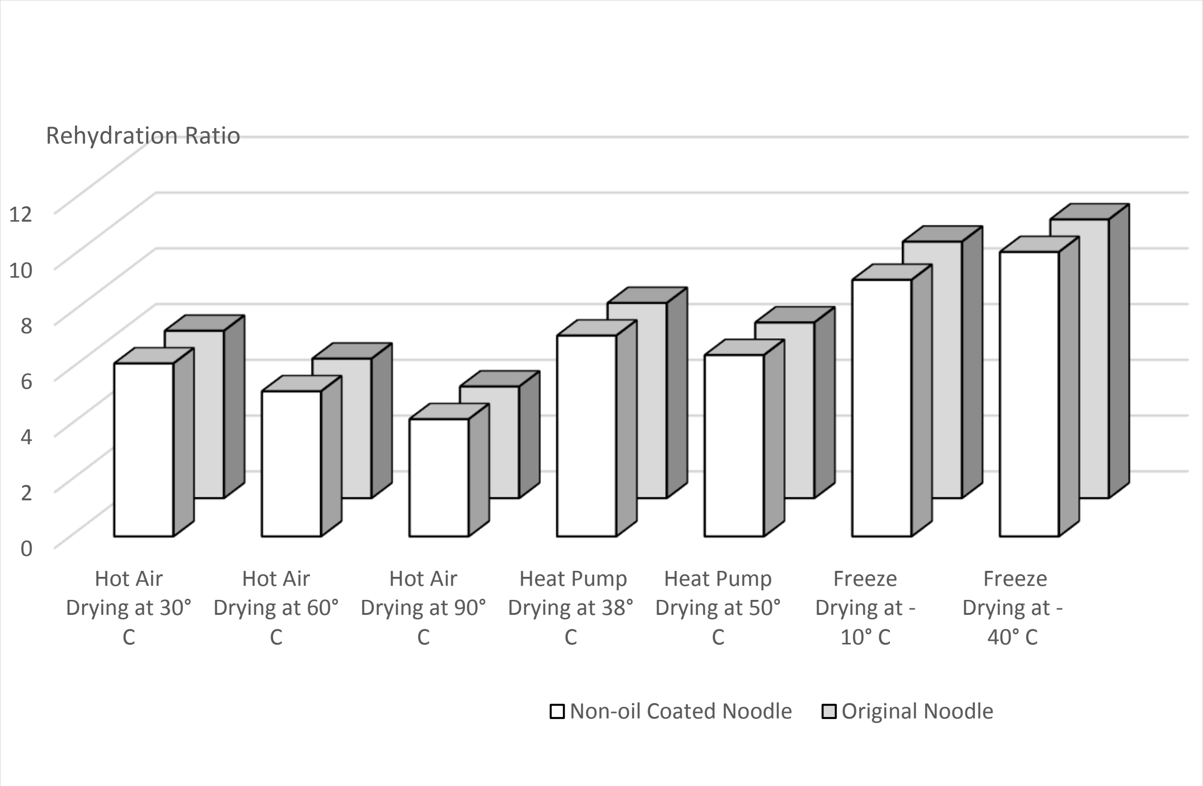


Figure 4.15 Overall rehydration ratio

It took an average of 6 minutes in rehydrating freeze dried sample fully, versus 8 minutes for hot air dried sample and 7.5 minutes for heat pump dried sample. From Figure 4.15, freeze drying sample recorded the highest rehydration ratio than other drying treatments. The freeze drying sample at -40 ^{0}C recorded the highest rehydration ratio by 7.8 for non-oil coated sample and 7.9 for the original sample. Meanwhile, the freeze drying sample at -10 ^{0}C recorded the rehydration ratio of 6.7 for non-oil coated sample and 6.9 for the original sample.

Higher rehydration ratio demonstrated by the freeze dried samples was mainly due to porosity. The formation of pores in the noodle makes it easy for the noodle to absorb water when it is soaked in hot water. Porosity will be discussed further when the microstructure of the dehydrated noodle is explained later in 4.3.6. From the microstructure, it could be observed that the pores in freeze-dried sample at -40 °C were smaller at 28.02 ± 6.81 μm to indicate higher porosity than the sample at -10 °C. Therefore, Figure 4.15 indicated that the rehydration ratio for that noodle sample was higher due to higher porosity.

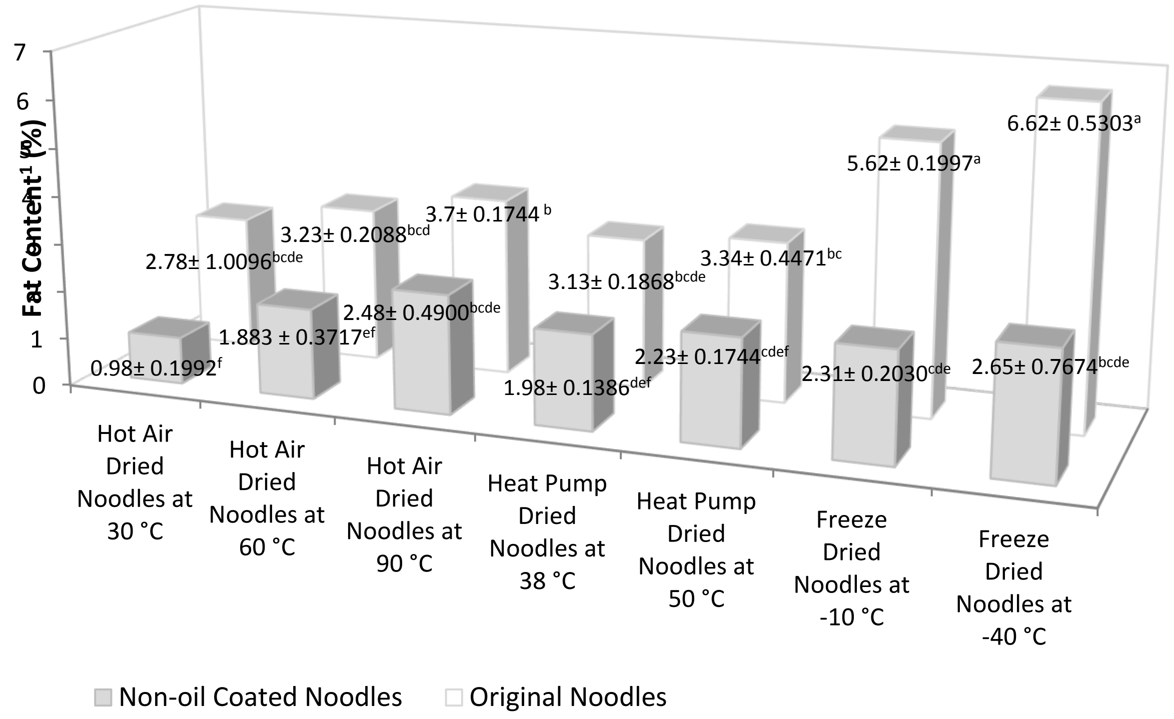
Heat pump drying sample recorded the average rehydration ratio in the range of 5.2 to 6.0. By observing the microstructure in heat pump dried noodle which will be discussed on Section 4.3.6, water can penetrate rehydration through shrinkage on the noodle surface. In the meantime, rice noodle subjected to hot air drying at different temperatures recorded the rehydration ratio in the range of 3.2 to 5.5. This poor rehydration ratio was attributed by the uniform collapse of cell structure with very limited pores to enable water penetration (Bhandari etal. 1999).

As can be observed from the previous Section, the gelatinization temperature, T_p of rice noodle subjected to hot air and heat pump drying was high. High T_p suggested that rice noodle was however partly gelatinized under normal steaming conditions (Hou 2010). In fact, the hard uncooked noodle in the soup as per discussed on the different time of full rehydration of noodle was due to the high amount of gelatinization left in the specific sample of rice noodle (Heussen et al. 2011). Hence, it is a challenge to promote the degree of starch gelatinization as it plays an essential role in determining the rehydration performance of the product.

Higher total rehydration ratio in freeze dried noodle corresponds to the low onset temperature of starch gelatinization, $T_{o.}$ The trends of rehydration ratio describe the pattern of starch gelatinization by observing the peak temperature of starch gelatinization, T_p. The lower gelatinization temperature of rice noodle subjected to freeze drying indicates faster gelatinization to occur to complete full rehydration which explains higher value of total rehydration ratio (Puspitowati et al. 2007).

4.3.5 Fat content

The fat content in noodle primarily depends on the type of wheat used, specific ingredients, as well as its processing method. Prior to performing drying experiment using different drying techniques, the fat content was determined by using Soxhlet analysis which was run for approximately 8 hours. The results are presented in Figure 4.16.



^{1}Means that do not share a letter are significantly different.

Figure 4.16 Fat content of rice noodle at drying variation

In Figure 4.16, non-oil coated noodle recorded low fat value of 0.9800 ± 0.1992 %, 1.8833 ± 0.3717 %, and 2.4800 ± 0.4900 % for hot air drying at 30 °C, 60 °C, and 90 °C, respectively meanwhile original noodle gave higher amount of fats which are 2.78 ± 1.0096 %, 3.23 ± 0.2088 % and 3.7000 ± 0.1744 % for 30°C, 60 °C, and 90 °C, respectively. Learning from the trends, lower hot air drying temperature on rice noodle extracted lower fat content. Indeed, long drying times with low drying temperature is the proof to the combinations of short drying time and low drying temperatures in analogous to prepare noodle of lower fat contents (Choy 2011).

Moreover, rice noodle is compulsorily coated with palm oil for the purpose of packaging. Its main purpose is to prolong its shelf life because it contains 45% of saturated fat and is more stable than oils with abundant unsaturated fats.

Therefore, the original dried sample of hot air drying gave a higher fat content because hot air drying merely produced concentrated stability of the coated oil on the original noodle (Kajihausa et al. 2014). This is because fresh foods are low in fats as in Table 4.8 which are slightly concentrated by drying process itself (Hou 2010). As the moisture content was removed in the drying process to result dehydrated rice noodle to be more concentrated source of calories and nutrients than the fresh rice noodle.

Table 4.8 The nutritional information of fresh rice noodle by Koperasi JML

Nutritional Information Serving Size: 100g	
Fat	1.00%
Protein	7.05%
Carbohydrate	32.75%
Energy	1.69%

Furthermore, non-oil coated noodle under heat pump drying recorded low fat percentage of 1.9800 ± 0.1386 % and 2.2300 ± 0.1744 % at 38 °C and 50 °C respectively meanwhile original noodle registered a higher amount of fats with the percentage of 3.1300 ± 0.1868 % and 3.3400 ± 0.4471 % at 38 °C and 50 °C. It was found that rice noodle sample for both original and non-oil coated dried at high temperature of 50 °C extracted higher amount of fat if compared to drying at 38 °C. This is due to the fact that oil at high temperature leads to rapid noodle declines thus favouring the oil absorption that may eventually prevent oil to escape during drying (Heldman 2003).

The original sample subjected heat pump drying gave a higher content of fat as compared to the non-oil coated noodle. This is because the pre-treatment process helps to lower the fat content in the rice noodle by removing the oil coating from the noodle surface. The fat content of rice noodle by hot air drying and heat pump drying is in the range of 1.0-3.0 % which is similar to the figures reported in the literature (Ross & Crosbie 2004).

On the other hand, freeze dried noodle recorded a higher percentage of fat content. Likewise, non-oil coated noodle recorded low fat percentage of 2.3100 ± 0.2030 % and 2.6500 ± 0.7674 % respectively at -10 °C and -40 °C meanwhile original noodle extracted a higher amount of fats with the percentage of 5.6200 ± 0.1997 % and 6.6200 ± 0.5303 % at -10°C, and -40 °C. The high content of fat was due to the fact that freeze drying preserves most nutrients including fats, where mono-saturated fats do not collapse at low temperature.

The differences in fat contents of the samples tested in this study could be due to gains during different drying processes. Several studies revealed that fat contents vary notably with storage time, raw materials and storage cycle of specific consumables (Ali et al. 2011). However it is worth to note that noodle with high fat content are vulnerable to oxidation and prone to development of fat rancidity. In this regard, freeze dried and hot air dried rice noodle are susceptible to notable fat oxidation during the storage period. Heat pump dried rice noodle on the other hand are expected to experience minimal fat oxidation during storage.

4.3.6 Microstructures

The study of microstructures has been useful to retrieve information about the particles behavior which may be incorporated with other characteristics such as texture, and cooking behaviour (or rehydation ratio) (Tudorică et al. 2002). The microstructures of fresh rice noodle at 500x magnification are presented as in Figure 4.17 below.

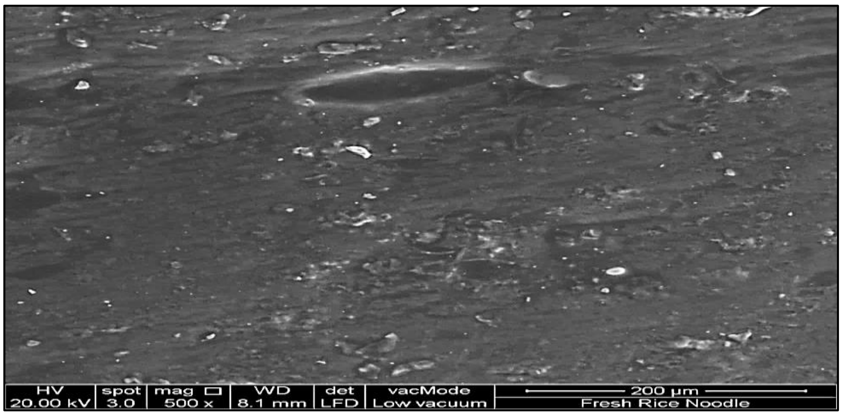
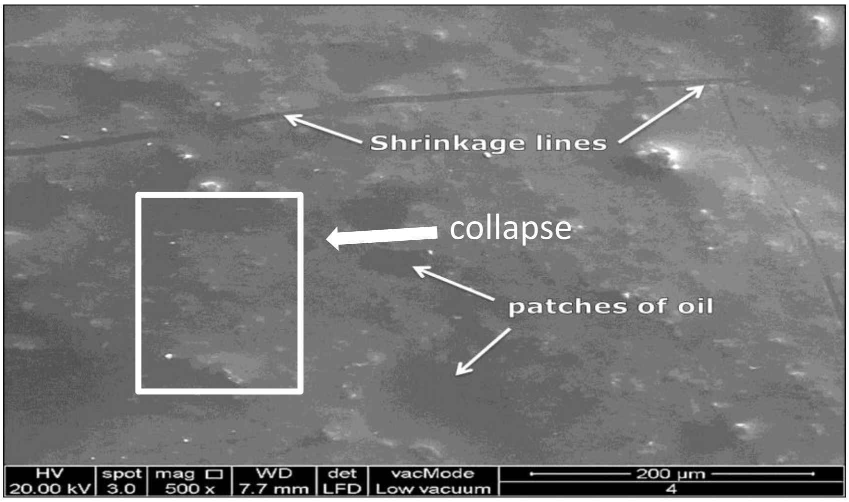
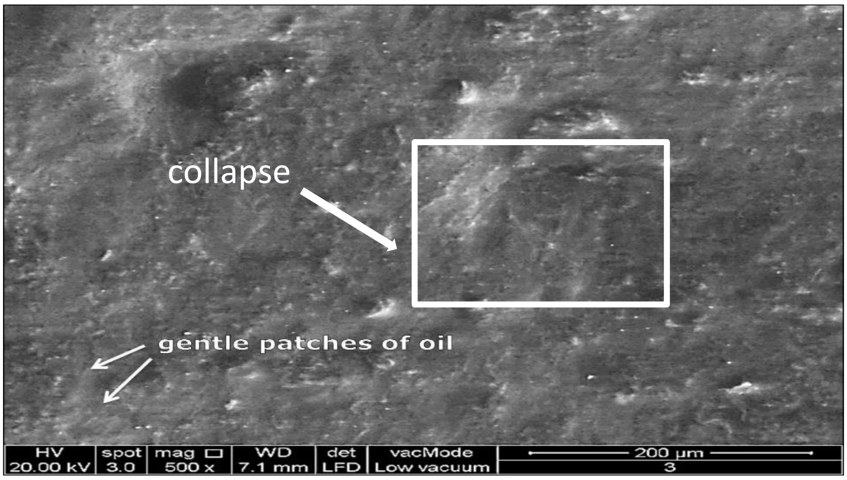


Figure 4.17 Microstructures of fresh rice noodle

The microstructure of fresh rice noodle is translucent with a consistent texture and several odds of bits due to incoherent flour blending. The texture remains intact without any declining integrity. However, several dark spots can be observed, which may indicate the existence of protein, starch, and oil.



(a)

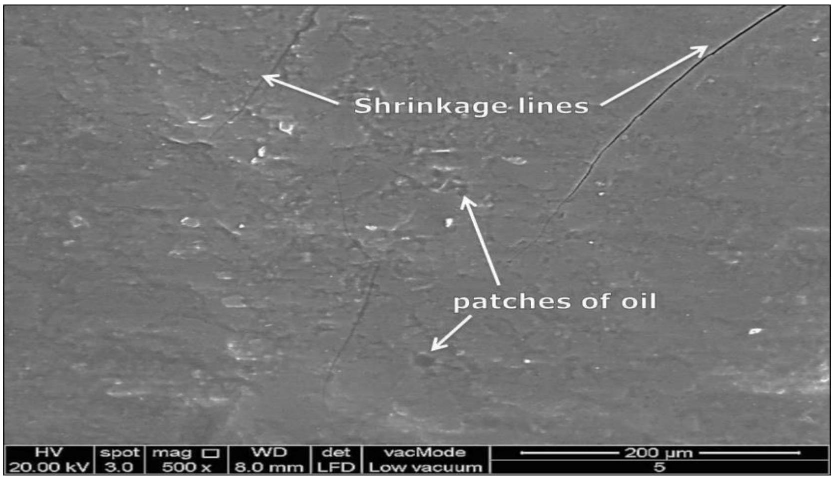


(b)

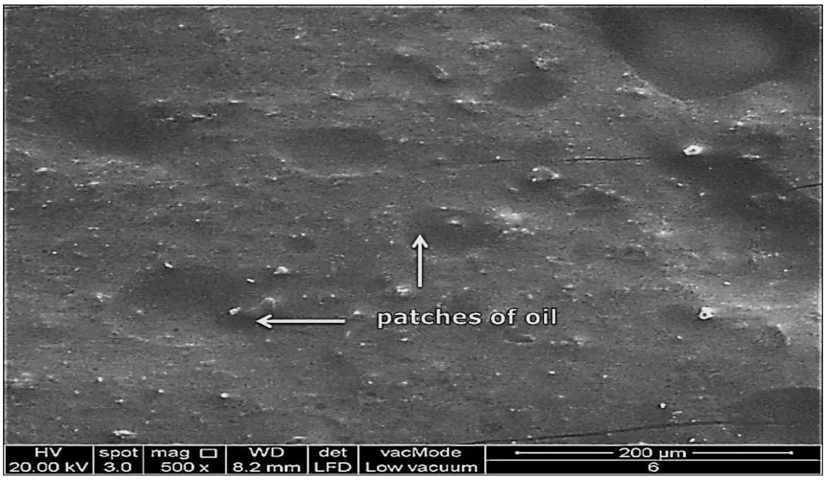
Figure 4.18 Microstructures of hot air dried for (a) non-oil coated noodle and (b) original noodle at 30 °C at 500 magnifications.

The microstructures of non-oil coated and original noodle subjected to different drying methods were observed. The microstructure of hot air dried noodle strand at 30 °C is shown in Figure 4.18. As reported by Fang et al. (2011), low drying temperature tends to show consistent shrinkage of declining intercellular lines. The uniform collapse of cell structure can be observed through the pieces on the surface with random patches of oil. More shrinkage allowed water penetration for better rehydration to occur as previously explained in Section 4.3.4.

The degree of cell structure where collapse and the number of random patches of oil is more serious on the surface of the original samples than the non-oil coated samples. The pre-treatment removed the oil content on the noodle surface hence the number of oil patches is reduced.



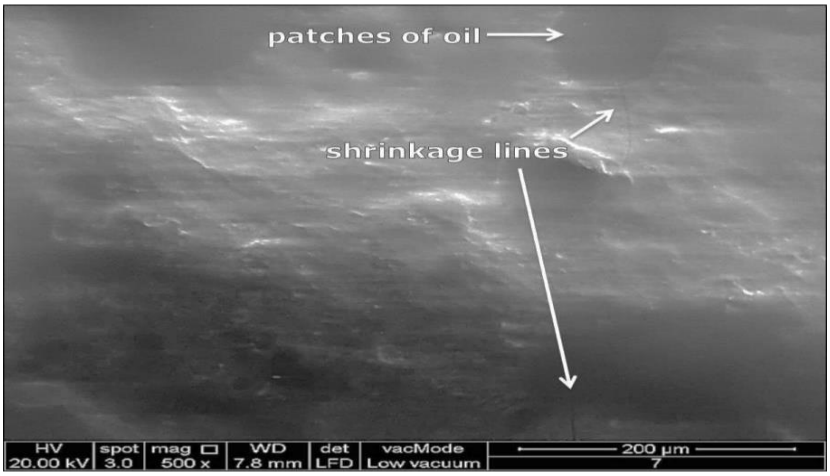
(a)



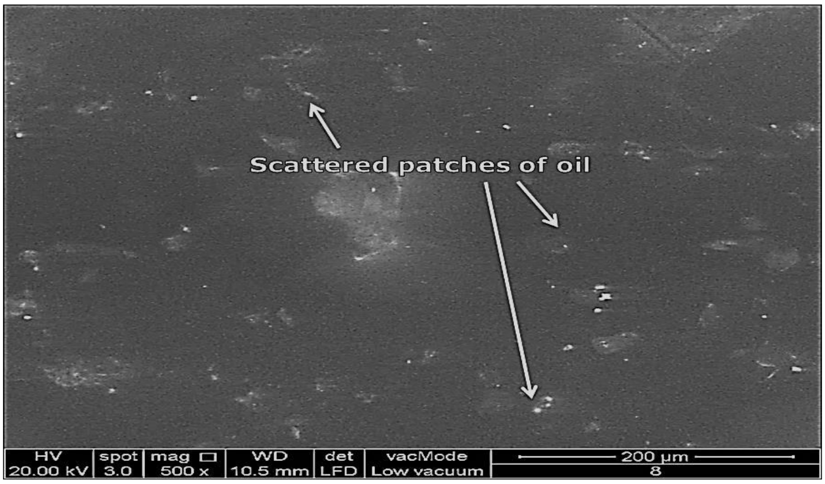
(b)

Figure 4.19 Microstructures of hot air dried for (a) non-oil coated noodle and (b) original noodle at 60 °C at 500 magnifications

Higher temperature causes higher shrinkage and more oil patches. Figure 4.19 shows the microstructures of rice noodle subjected to hot air drying at 60 °C. It can be observed that the noodle surface is a little rougher and experience slightly higher degree of shrinkage than the samples subjected 30 °C. This is definitely due to the higher temperature which induces such occurrence to the noodle microstructures. This corresponds well to a similar study conducted on rice noodle in the drying temperature range of 40-70 ºC in Thailand whereby different drying temperature does not inhibit any significant difference in the morphology being observed (Kongkiattisak & Songsermpong 2012).



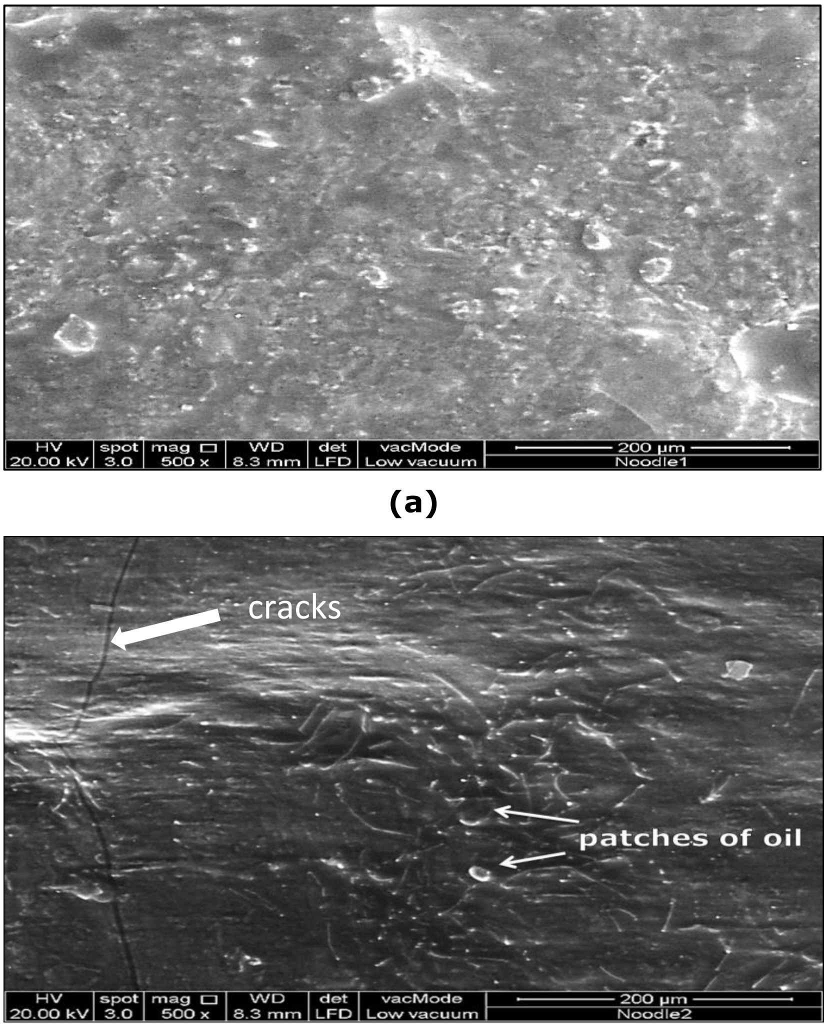
(a)



(b)

Figure 4.20 Microstructures of hot air dried for (a) non-oil coated noodle (b) original noodle at 90 °C at 500 magnifications.

However, the microstructures of non-oil coated and original dried noodle strands under hot air drying at 90 °C as in Figure 4.20 have shrinkage and patches of oil. Its surface is smoother and more even than rice noodle subjected to hot air drying at 60 °C and 30 °C. The presence of scattered shrinkage patches of oil due to the rapid drying indicates the scattered position of fatigue points. The rapid structural transition induces fatigue points to the structure. This corresponds to a higher breakability. The fatigue may grow during storage and causes the breakability to be even worse. Matsuo et al. (1978) reported that starch on the surface of hard pasta shrank due to thermal drying. It was found in this study that oil also shrunk as the drying temperture increases.

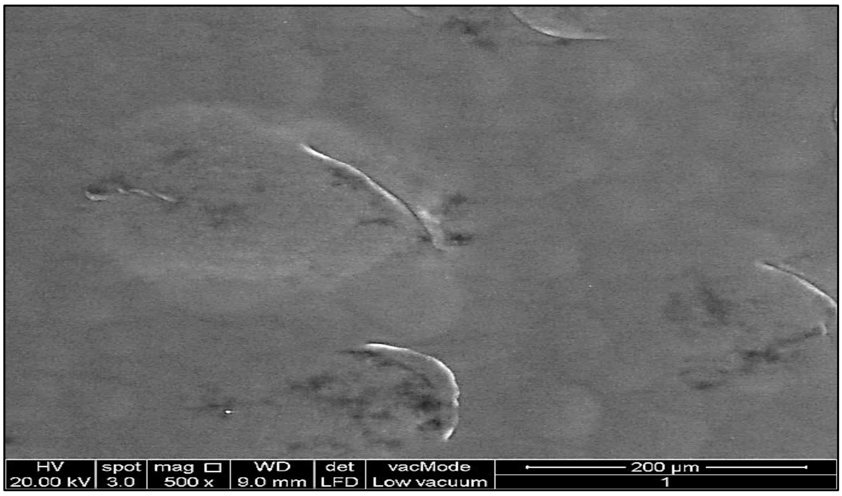


(a)

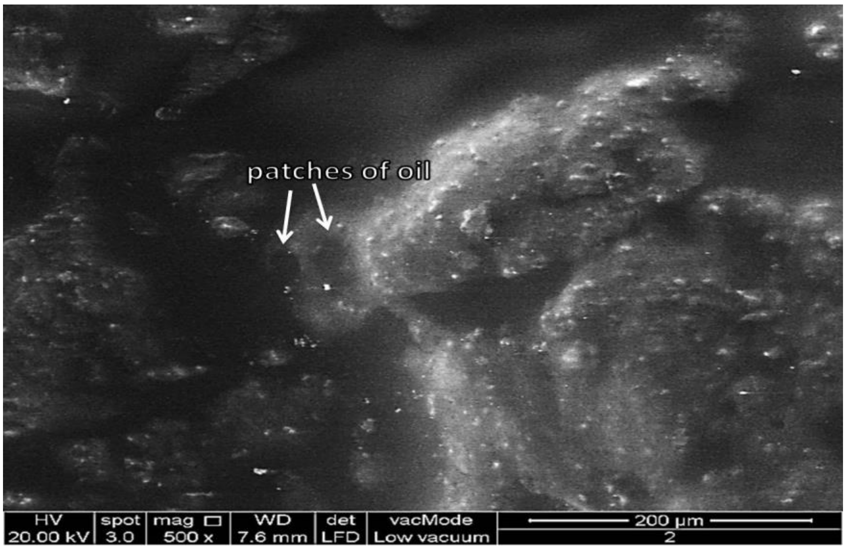
(b)

Figure 4.21 Microstructures of heat pump dried for (a) non-oil coated noodle and (b) original noodle at 38 °C at 500 magnifications (heater off).

From Figure 4.21, scattered images can be spotted through higher magnifications for both non-oil coated and original noodle strand undergoing heat pump drying. This is probably due to the strong air velocity circulating inside the drying system to cause the structural inconsistency. Moreover, compact internal structure were observed in original noodle in Figure 4.21 (b) under higher magnifications. During heat pump drying, internal cells remain intact with shrinkage stresses pull the thin layer tissue apart at the external.



(a)

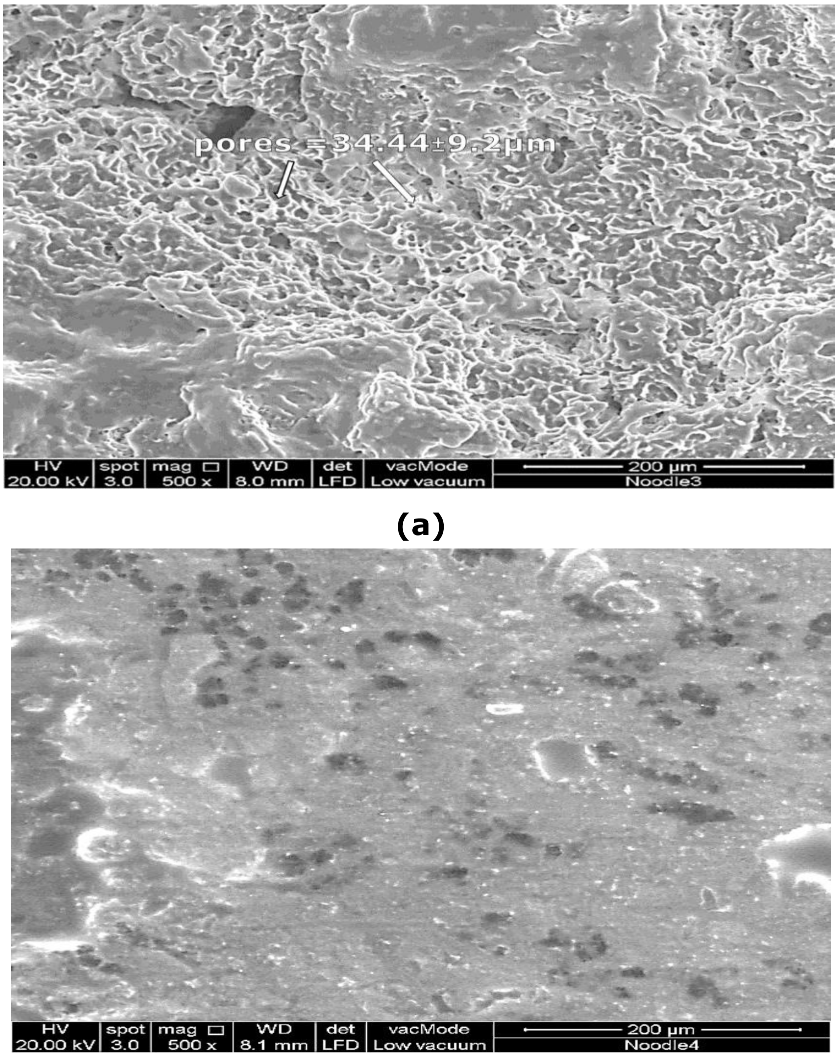


(b)

Figure 4.22 Microstructures of heat pump dried for (a) non-oil coated noodle and (b) original noodle at 50 °C at 500 magnifications.

By operating heat pump drying at 50 °C, it produced a glassy dehydrated noodle due to shorter drying period and under relatively high temperature (Figure 4.22). Wavy texture can be seen for both oil coated and original noodle. Generally, the microstructures of the non-oil coated noodle of heat pump drying at both 38 and

50 °C are smoother than the original noodle due to less oil content on the noodle surface. The existance of oil on the surface of the noodle may cause un-even heat and mass transfer behaviour during the drying process. As the non-oil coated has less oil content on the surface, the noodle matrix is uniform and when it is subjected to heat treatment such as drying, the dehydration and the shrinkage is more uniform hence the surface is smoother.



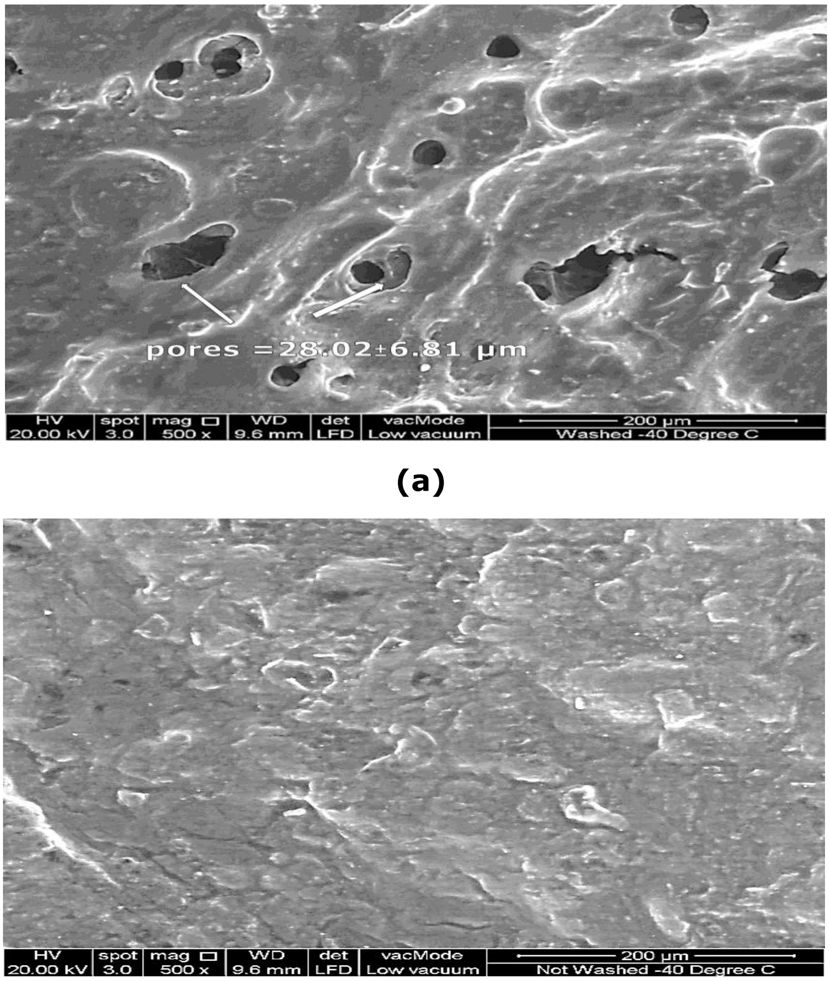
(a)

(b)

Figure 4.23 Microstructures of freeze drying for (a) non-oil coated noodle and (b) original noodle at -10 °C at 500 magnifications

The microstructures of non-oil coated and original rice noodle subjected to freeze drying respectively at -10°C and -40°C are shown in the following figures. In Figure 4.23 (a), there are some large spherical voids in the noodle which may have been formed by the ice crystals during freezing. The SEM images of freeze dried non-oil coated noodle at -10 °C showed uniform large pores at an average of 34.44 ± 9.20 µm whereby strong firmness can be deduced in such textural observance.

Resmini & Pagani (1983) reported that porous structure embedded with starch granules tends to give stronger binding forces. The porous structure embedded with the starch granules on the surface of freeze dried noodle are hugely influenced by the concentrated starch amylose content (Gulia et al. 2014). In the meantime, original noodle subjected to freeze drying gave more uniform structure with less embedded starch granules evident by smaller air cells with no significant pores shown in Figure 4.23 (b).



(a)

(b)

Figure 4.24 Microstructures of freeze drying for (a) non-oil coated noodle and (b) original at -40 °C at 500 magnifications

The perforated cell walls of rice noodle under freeze drying at-40 °C are well notable for non-oil coated noodle strand as shown in Figure 4.24 (a). The microstructures of non-oil coated sample conformed to an average pore size of 28.02 ± 6.81, lower than freeze drying at -10 ºC. This microstructural behaviour is largely due to the gentle drying temperature introduced to the noodle at -40 C. Indeed, it has reflected a more consistent structure at lower pore size to create more numerous voids as in Figure 4.24 (b) compared to the freeze drying under -10 °C. This structural disruption is significantly attributed to the fact that oil inside noodle escapes in a random way due to hydrophobicity prior to pre-treatment process.

Microstructural changes are always correlated to textural attributes especially the hardness value (Tudorică et al. 2002; Marsilio et al. 2000). The textural properties are primarily affected by cellular organelles and biochemical constituents, water content, and cell wall composition. Since texture is the results of complex interactions among food components, the very low temperature in freeze drying has halted the chemical activities that lead to negligible shrinkage which contributed to its superior amount of hardness value (Bharath Kumar & Prabhasankar 2015; Pei et al. 2014).

4.3.7 Sensory Evaluation

Sensory assessment for product quality has essentially become an important aspect of a quality control regime (Lawless & Heymann 2010). Table 4.9 lists the sensory scores given by panels on various organoleptic properties of cooked rice noodle from dehydrated noodle processed by different drying methods.

Indeed, freeze drying increased (p>5%) the sensory scores in terms of colour and surface smoothness of rice noodle significantly. As the colour scores of fresh noodle is 3.053 ± 1.026, the colour scores of freeze dried rice noodle was ranging from 3.421 ± 0.961 to 3.789 ± 1.228 which scored very well. Meanwhile, the colour of heat pump dried noodle was depicted at 2.474 ± 0.841.

Table 4.9 Sensory scores of various organoleptic properties of cooked rice noodle

Sample	**Colour**	**Surface Smoothness**	**Textural Smoothness**	**Oil and Fat Appearance**	**Elasticity**	**Taste**
Fresh Rice Noodle	3.053 ± 1.026^{abcde}	4.053 ± 0.911^{a}	3.947 ± 0.970^{a}	3.421 ± 1.170^{a}	3.000 ± 1.000^{a}	2.526 ± 1.172^{a}
Non-oil coated Hot Air Drying at 30 °C	2.105 ± 0.658^{e}	2.105 ± 0.737^{d}	2.105 ± 0.937^{d}	3.211 ± 1.134^{ab}	3.695 ± 1.696^{a}	2.316 ± 0.946^{a}
Original Hot Air Drying at 30 °C	2.263 ± 1.098^{de}	3.000 ± 1.000^{abcd}	2.842 ± 0.898^{abcd}	3.000 ± 1.633^{ab}	3.684 ± 1.157^{a}	2.684 ± 1.108^{a}
Non-oil coated Hot Air Drying at 60 °C	3.105 ± 0.937^{abcde}	3.263 ± 1.098^{abcd}	3.474 ± 0.964^{abc}	2.737 ± 0.991^{ab}	3.105 ± 0.809^{a}	3.263 ± 1.046^{a}
Original Hot Air Drying at 60 °C	2.579 ± 1.305^{bcde}	3.211 ± 0.918^{abcd}	2.895 ± 0.937^{abcd}	2.737 ± 1.284^{ab}	3.053 ± 1.026^{a}	2.895 ± 1.150^{a}
Non-oil coated Hot Air Drying at 90 °C	3.053 ± 1.079^{abcde}	2.684 ± 0.885^{cd}	3.053 ± 1.026^{abcd}	3.053 ± 0.970^{ab}	3.263 ± 1.284^{a}	2.895 ± 1.100^{a}
Original Hot Air Drying at 90 °C	3.105 ± 0.809^{abcde}	2.737 ± 1.195^{abcd}	2.684 ± 1.108^{bcd}	2.842 ± 1.167^{ab}	3.195 ± 1.243^{a}	2.947 ± 1.079^{a}

Sample	Colour	Surface Smoothness	Textural Smoothness	Oil and Fat Appearance	Elasticity	Taste
Non-oil coated Heat Pump Drying at 38 °C	2.842 ± 1.214^{abcde}	3.579 ± 1.017^{abc}	3.263 ± 1.046^{abcd}	2.842 ± 1.344^{ab}	3.368 ± 0.831^{a}	2.789 ± 1.084^{a}
Original Heat Pump Drying at 38 °C	2.737 ± 1.195^{abcde}	3.158 ± 1.385^{abcd}	2.684 ± 1.336^{bcd}	2.105 ± 0.809^{b}	3.053 ± 1.353^{a}	2.789 ± 1.228^{a}
Non-oil coated Heat Pump Drying at 50 °C	2.474 ± 0.841^{bcde}	3.105 ± 1.197^{abcd}	2.737 ± 1.046^{bcd}	3.421 ± 0.961^{a}	3.205 ± 1.197^{a}	2.789 ± 1.182^{a}
Original Heat Pump Drying at 50 °C	2.947 ± 1.177^{abcde}	2.947 ± 0.970^{abcd}	2.789 ± 1.084^{abcd}	3.211 ± 1.032^{ab}	3.111 ± 1.084^{a}	2.684 ± 1.157^{a}
Non-oil coated Freeze Drying at -10 °C	3.789 ± 1.228^{a}	3.421 ± 1.216^{abc}	3.211 ± 1.182^{abcd}	2.947 ± 1.079^{ab}	2.987 ± 1.264^{a}	3.368 ± 1.116^{a}
Original Freeze Drying at -10 °C	3.579 ± 1.121^{ab}	3.947 ± 1.177^{a}	3.158 ± 1.214^{abcd}	2.789 ± 1.398^{ab}	2.968 ± 1.383^{a}	3.158 ± 1.259^{a}
Non-oil coated Freeze Drying at -40 °C	3.474 ± 1.219^{abc}	3.895 ± 0.875^{ab}	3.632 ± 1.065^{ab}	3.316 ± 1.108^{ab}	2.989 ± 1.427^{a}	3.000 ± 1.333^{a}
Original Freeze Drying at -40 °C	3.421 ± 0.961^{abcd}	3.684 ± 0.749^{abc}	3.737 ± 0.991^{ab}	3.421 ± 0.838^{a}	2.953 ± 1.129^{a}	3.263 ± 1.195^{a}

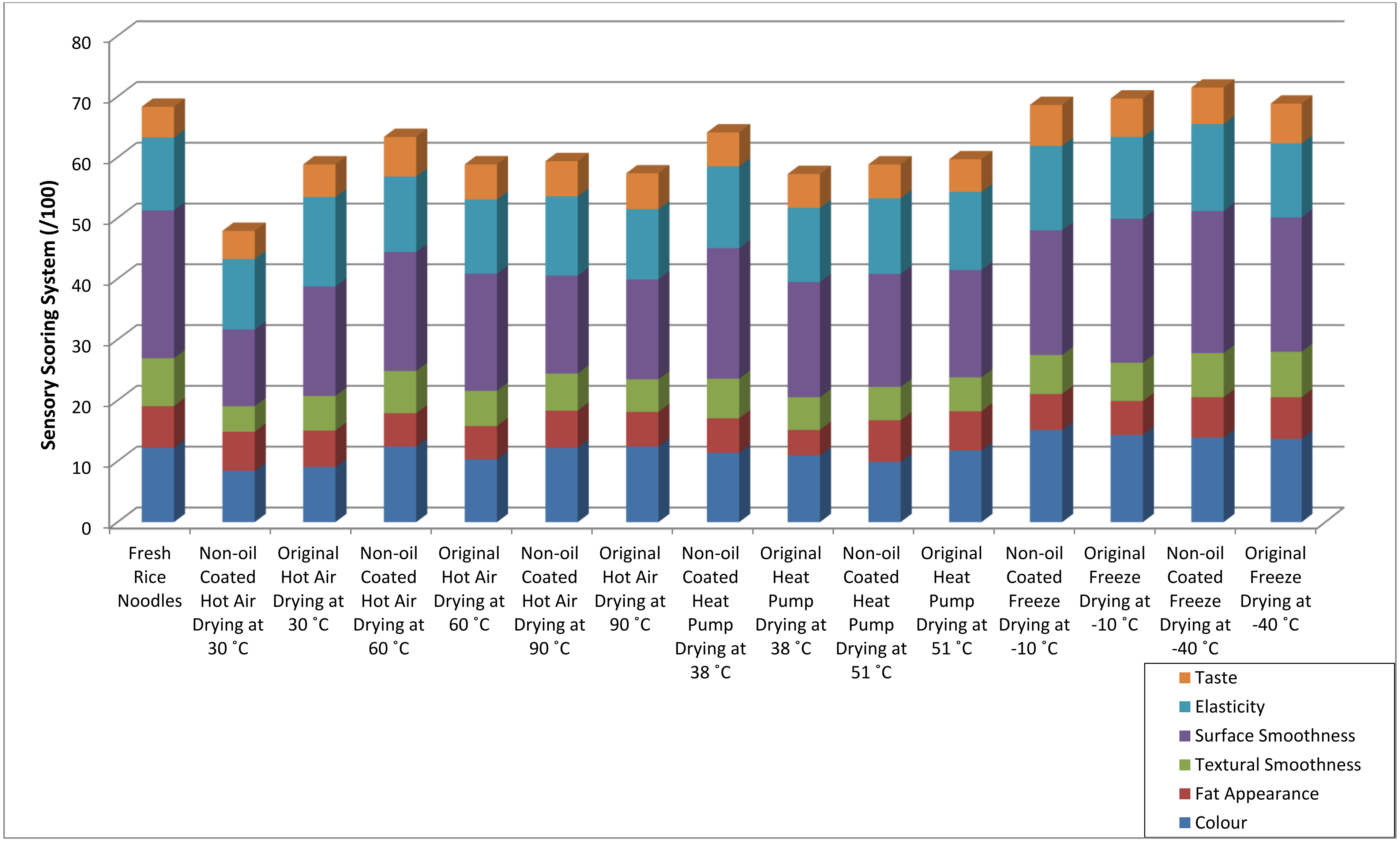


Figure 4.25 Cumulative sensory scores of various organoleptic properties of cooked rice noodle

As freeze drying is highly reliable in closely preserving the colour of rice noodle has confirmed the fact that freeze-dried materials are usually distinguished by superior-quality attributes including texture, overall rehydration, and colour (Voda et al. 2012).

In addition to that, the colour of the cooked noodle in the sensory evaluation corresponds well to the colour selection of dried noodle by measurement (Zieliñska et al. 2005). In parallel to being superior in total colour change of dried noodle, rice noodle subjected to freeze drying recorded the highest scores in the colour attributes of sensory evaluation test. The closest resemblance of cooked freeze-dried noodle to fresh rice noodle was deemed to be appealing to sensory panels. It defines the preservation of high quality of rice noodle prior to cooking in terms of colour attributes.

On the contrary, the surface smoothness of fresh rice noodle scored 4.053 ± 0.911, whereas freeze dried noodle falls between the ranges of 3.421 ± 1.216 to 3.947 ± 1.177. This is mainly due to the formation of ice crystals from the inside and outside the cells during the freezing process which incurred pores on the latter drying surface. Furthermore, the surface smoothness of both hot air and heat pump dried noodle recorded the range of 2.105 ± 0.737 to 3.263 ± 1.098. This is due to the heat treatment that disrupts the starch granules to induce more inconsistent shrinkage cells (Zhang et al. 2011).

On the contrary to the surface smoothness of the hot air dried rice noodle, the textural smoothness has a lower score ranging from 2.105 ± 0.9372 to 2.842 ± 0.898. This indicates that hot air dried noodle has smoother noodle surface compared to the internal structure. However, the lowest textural smoothness evaluation is recorded by the heat pump dried noodle ranging from 2.684 ± 1.336 to 3.263 ± 1.084. Low sensory scores on its textural smoothness recorded by heat pump dried noodle was in agreement with the lower hardness value compared to the hot air dried noodle.

All in all, the drying condition does not ($p<5\%$) significantly affect the oil and fat content. As referencing to the fat appearance of the fresh rice noodle at 3.421 ± 1.170, the fat appearance of other drying methods generally range from 2.105 ±

0.809 to 3.421 ± 0.961. Indeed, the temperature of hot air drying is independent to the perceived fat appearance of the noodle which is ranging from 2.737 ± 1.344 to 3.211 ± 1.134.

The sensory panels scored the fat content in cooked dried rice noodle to be at the average of 2.955 ± 0.678 in comparison to the scores of cooked fresh rice noodle at 3.421 ± 1.17. Therefore, the scores of fat content in cooked rice noodle regardless drying treatment were in parallel to the fat content in fresh noodle. Despite the fat content percentage of rice noodle subjected to different drying treatments is higher as per discussed in Section 4.3.5, its actual fat content is apparently not significantly different from the fresh sample. Therefore it corresponds well to why it does not significantly change the perceived fat content scores of cooked dried noodle in regards to the cooked fresh rice noodle.

Furthermore, the drying treatment did not (p<5%) significantly affect the taste and elasticity of the rice noodle. By scoring 3.000 ± 1.00 for the elasticity, the fresh rice noodle seems to be perceived as less chewy than the other drying treatments. Freeze dried noodle scored better in elasticity in the range of 3.053 ± 1.129 to 3.474 ± 1.264. Indeed, the swelled starch of rice noodle subjected to rehydration was in account to the elasticity and firmness of noodle. This is in agreement to the optimally cooked starch noodle to be either not too hard or too smooth (Gatade & Sahoo 2015).

Baik & Lee (2003) reported that the elastic and soft texture of Japanese white salted noodle or Udon, is proportional to its amylose content and gelatinization temperature. Generally, the gelatinization temperature of rice noodle is in agreement to the scores of elasticity in sensory evaluation test. In this study, freeze drying significantly lowered the gelatinization temperature that they scored lower in the elasticity attribute in the sensory evaluation test. Indeed, the gelatinization temperature describes the heat stability of crystallites whereby the ΔH value is highly correlated with the molecular order and crystallinity. Therefore, the structural disruption which is attributed to the crystalline network or the reduction of double helices might have occurred during freeze drying.

Finally, hot air drying and heat pump drying are perceived to be highly acceptable in the sense of taste in comparison to the fresh rice noodle itself. Indeed, the results reveals that the fresh rice noodle scored a value of 2.526 ± 1.172 in taste attribute, whereas the hot air and heat pump drying scored an average of 2.895 ± 1.100. This indicates that cooked noodle prepared from the dehydrated form is acceptable to consumers. On the other hand, rice noodle subjected to freeze drying scored the best in the range of 3.000 ± 1.333 to 3.368 ± 1.116. The overall perceived taste recorded by rice noodle in the study is in agreement to the sensory scores reported by Ritthiruangdej et al. (2011b) to suggest the taste of cooked dried noodle was not that significant by different drying methods.

The scores from the hedonic scales are tabulated as in Figure 4.25 according to colour (20%), surface smoothness (15%), textual smoothness (15%), oil/fat content (10%), elasticity (25%), and taste/flavour (15%) (Fu 2008). The taste scores from the sensory evaluation for both non-oil coated and oil coated (original) cooked rice noodle gave the same value, at the same time the scores for fresh and dried noodle (hot air and heat pump drying) are not significantly different; therefore from the consumer health point of view, it is better to produce dehydrated rice noodle using pre-treatment to reduce its oil content. Clearly, freeze drying gave even higher taste scores, hence it can be considered as a good drying technique in producing dehydrated rice noodle in subject to sensory evaluation.

4.4 OVERALL EVALUATION

The results of the quality attributes subjected to hot air drying (HAD), heat pump drying (HPD), and freeze drying (FD) are discussed in section 4.3.1 – 4.3.7 and is summarised in Table 4.10.

Table 4.10 The Overall Quality Assessment of Rice Noodle

Treatment			**Texture**	**Colour**	**Starch**	**Fat content**	**Rehydration ratio**	**Microstructure**	**Sensory Evaluation**
HAD	30 °C	Non-oil Coated	Medium	Glass	High	Low	Medium	High Shrinkage	Poorly Accepted
		Original	Medium	Glass	High	Medium	Medium	High Shrinkage	Poorly Accepted
	60 °C	Non-oil Coated	Medium	Glass	High	Low	Medium	Medium Shrinkage	Accepted
		Original	Fragile	Glass	High	Medium	Medium	Medium Shrinkage	Accepted
	90 °C	Non-oil Coated	Fragile	Glass	High	Medium	Low	Shrinkage	Accepted
		Original	Fragile	Glass	High	High	Low	Shrinkage	Poorly Accepted
HPD	38 °C	Non-oil Coated	Medium	Glass	Medium	Low	Medium	Seamless	Accepted
		Original	Medium	Glass	Medium	Medium	Medium	Seamless	Poorly Accepted
	50 °C	Non-oil Coated	Fragile	Glass	Medium	Low	Low	Seamless	Accepted
		Original	Fragile	Glass	Medium	High	Low	Seamless	Accepted
FD	-10 °C	Non-oil Coated	Hard	Opaque	Low	Medium	High	Highly Porous	Highly Accepted

		Original	Hard	Opaque	Low	High	High	Porous	Highly Accepted
	-40 °C	Non-oil Coated	Hard	Opaque	Low	Medium	High	Highly Porous	Highly Accepted
		Original	Hard	Opaque	Low	High	High	Porous	Highly Accepted

In term of rice noodle overall performance by taking into account 7 quality attributes discussed earlier, the noodle of high quality must have radiant colour, long shelf life with no rancidity, and great textural and cooking characteristics (Ahmed et al. 2016). For each parameter, the noodle samples were ranked according to the exact values of hardness, colour analysis, starch gelatinization, rehydration ratio, fat content and sensory evaluation. The marks were then tabulated whereby microstructures were then justified.

In regards to that, rice noodle subjected to freeze drying regardless the drying conditions scored the best marks in the overall quality evaluation. This is followed by rice noodle subjected to heat pump drying at 38 °C which recorded acceptable scores in all quality attributes whereby the marks of rice noodle subjected to hot air and heat pump drying at different drying conditions were relatively close. Therefore, the study of transparency phenomena which can be observed in rice noodle subjected to hot air and heat pump drying will be discussed in Section 4.5 in order to learn the effects towards the actual overall quality evaluation.

Despite scoring in most quality attributes, freeze dried rice noodle however have high porosity to eventually cause microbial spoilage which will be discussed in Section 4.6. High porosity is the limiting factor to hugely restrict the product shelf life by promoting mold growth (Choy 2011). Therefore freeze dried rice noodle is merely preferred due to its superior quality attributes.

4.5 TRANSPARENCY PHENOMENA

The transparency of noodle is regarded as one of the most important appearance attributes of dried noodle that hugely determines the marketability of specific noodle product (Tan et al. 2009). The transparency phenomenon of dehydrated noodle can be inspected by looking at its physical appearance and analysed by referring to its colour analysis and starch gelatinization.

The image of the rice noodle subjected to hot air drying, heat pump drying, and freeze drying is presented in Figure 4.26.

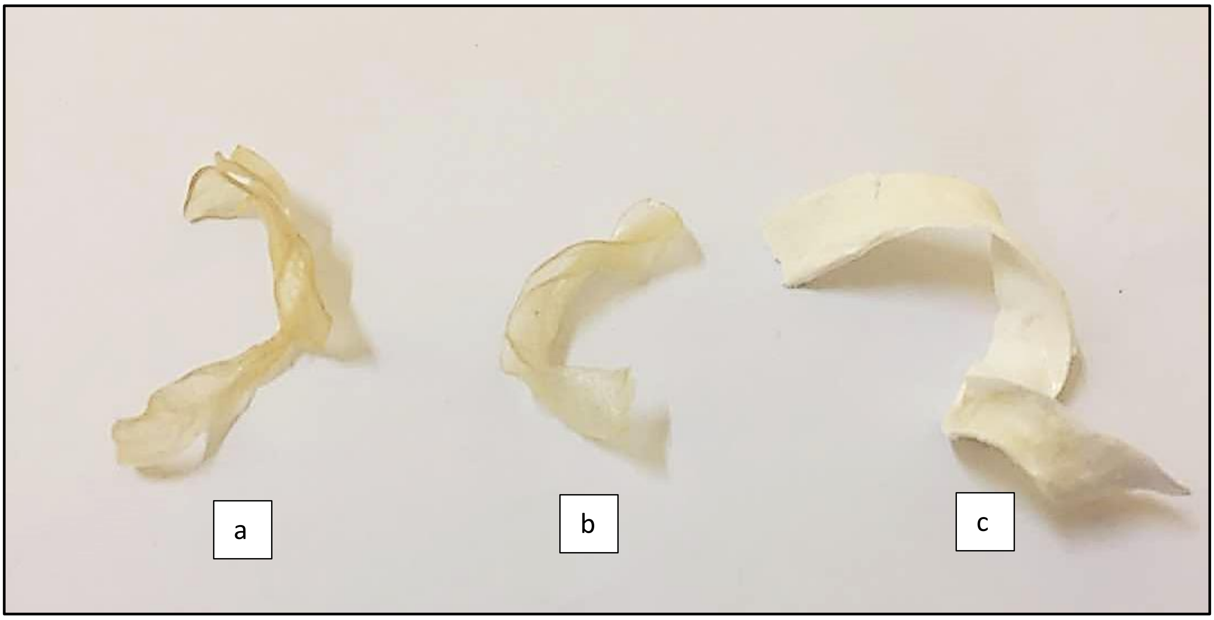


Figure 4.26 Physical Inspection of Dried Noodle subjected to (a) hot air drying, (b) heat pump drying, and (c) freeze drying

Figure 4.26 shows that the freeze drying sample of rice noodle is solid white in colour. In the meantime, hot air drying and heat pump drying produced the rice noodle of high transparency. From the colour analysis, freeze dried gave positive ΔL value whereas transparent dehydrated rice noodle gave negative ΔL value. The ΔL values of dehydrated rice noodle subjected to three different drying methods are presented in Table 4.11. The L^* value of fresh rice noodle was found to be 72.0 in the colour analysis. As the L^* values of freeze-dried samples are higher to approach 100, it gives a ΔL that is positive which indicates bright colour and it is opaque (Tan et al. 2009). In the meantime, the hot air drying and heat pump drying of rice noodle recorded lower L^* than 72.0 which gives a negative ΔL value, which indicates that the colour of hot air and heat pump dried rice noodle is not white and opaque.

Table 4.11 The *ΔL* values of rice noodle subjected to three drying methods.

Drying Treatment	**ΔL**
Non-oil Coated Hot Air Dried Noodle at 30 °C	-27.567± 3.350^{b}
Original Hot Air Dried Noodle at 30 °C	-34.433± 2.970^{bc}
Non-oil Coated Hot Air Dried Noodle at 60 °C	-36.033± 5.121^{bc}
Original Hot Air Dried Noodle at 60 °C	-36.400± 5.977^{bc}
Non-oil Coated Hot Air Dried Noodle at 90 °C	-42.900± 2.193^{c}
Original Hot Air Dried Noodle at 90 °C	-44.500± 6.144^{c}
Non-oil Coated Heat Pump Dried Noodle at 38 °C	-41.033± 4.200^{c}
Original Heat Pump Dried Noodle at 38 °C	-42.000± 4.503^{c}
Non-oil Coated Heat Pump Dried Noodle at 50 °C	-42.867± 2.875^{c}
Original Heat Pump Dried Noodle 50°C	-45.500± 3.396^{c}
Non-oil Coated Freeze Dried Noodle at -10 °C	22.733± 1.301^{a}
Original Freeze Dried Noodle at -10 ° C	17.433± 3.281^{a}
Non-oil Coated Freeze Dried Noodle at -40 °C	18.933± 1.222^{a}
Original Freeze Dried Noodle at -40 ° C	17.700± 1.670^{a}

Similar to the trends in hot air drying, as the temperature of heat pump drying increases, the colour changes are getting more distinct (Hu et al. 2006). The heat pump drying at higher air velocity also cause significant colour change to the noodle to eventually degrade the overall food colour quality. Higher air velocity tends to further trigger oxidative reactions and enzymatic browning to cause the brown stain of the dried products due to the Maillard reaction (Zhu et al. 2010). The Maillard reaction is activated at sufficient heat between amino acids and reducing sugars (starch) in the noodle to cause non-enzymatic browning reaction (Martins et al. 2000).

The effects in noodle transparency can be due to the changes in phosphate monoester derivatives and phospholipids contents within the starches at high temperature between the onset temperature, T_o and the glass transition temperature, T_g (Jane et al., 1996). The degree of transparency is influenced by the source of starch of the noodle (Chen et al. 2002). For rice noodle, T_g is in the range of 29 °C to 110 °C. Subjecting rice noodle at the temperature higher than T_g will only result the noodle to be in the rubbery state like a bowl of cooked noodle. Below T_g, the noodle are in glassy state. Therefore dehydrated rice noodle by hot air and heat pump drying are glassy. Whereas dehydrated rice noodle by freeze drying which were carried out at the temperature which is below the collapse temperature (-5 °C).

In the meanwhile, subjecting rice noodle at the temperature lower than T_g'(maximally freeze-concentrated glass transition temperature) is important to the stability of frozen food whereby shrinkage is negligible and more pores were formed. Indeed, it is also referred to as *collapse temperature* which is -5.3°C for stick rice noodle, the point below which the product must maintain to prevent the melt-back or collapse during primary drying to further describe the freeze-dried rice noodle (Kamolwan, 2016). In this regards, the glassy state is available until the maximally freeze-concentrated state is achieved.

Therefore, the transparency phenomenon of rice noodle has been well defined by glass transition theory, physical inspection and colour analysis. Indeed, the transparency phenomenon described the rice noodle subjected to hot air and heat pump drying to influence the overall quality preference compared to freeze drying in particular to starch gelatinization and texture behaviour. The rice noodle subjected to freeze drying has higher porosity which makes it more susceptible to oxygen. Indeed, lipid oxidation is vulnerable to the bacterial spoilage which is truly not favourable for any food product. The further effects of this porosity may be observed clearly from the stability test which will be explained in Section 4.6.

4.6 STABILITY TEST

The fact that dried noodle is a very hygroscopic food product whereby it tends to absorb moisture easier (Dixit et al. 2012). A good dried product must be able to preserve its current dried condition without significant quality degradation in particular of microbial spoilage. Therefore, in order to determine the best product subjected to the drying process, the stability test was conducted at 30 °C for more than 3 months.

Figure 4.27 Real time stability test at 30 °C for more than 3 months for the rice noodle subjected a) hot air drying b) heat pump drying c) freeze drying

By observing the dried noodle subjected to hot air drying, heat pump drying, and freeze drying after more than 3 months as in Figure 4.27, the microbial spoilage was severe in freeze drying followed by hot air drying at 30 °C. However, the microbial spoilage in rice noodle subjected to heat pump drying at 38 °C could not be observed.

This could be explained by the equilibrium moisture content, m_e which is the final moisture content in the noodle sample. The m_e for rice noodle subjected to hot air drying, freeze drying and heat pump drying was 0.168, 0.085, and 0.200 respectively. As the minimum moisture content to support microbial growth was 0.12, therefore it can be observed that the microbial growth behave accordingly (Compliance 1980). The finding on stability test has confirmed the transparency phenomenon in rice noodle to be able to preserve the shelf life of the sample.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

1. The drying kinetics of rice noodle dehydrated by both hot air and heat pump drying methods has been studied. The effective diffusivities resulted for the first falling rate of non-oil coated and original rice noodle subjected to hot air drying at 30 °C are 1.60 x 10^{-11} m^2/s, and 1.25 x 10^{-11} m^2/s, respectively. The effective diffusivities obtained for the second falling rate of the respective non-oil coated and original rice noodle at 30 °C are 2.20 x 10^{-11} m^2/s, and 1.71 x 10^{-11} m^2/s. The effective diffusivities resulted for the first falling rate of original rice noodle at 60 °C and 90 °C are 6.35 x 10^{-11} m^2/s and 1.26 x 10^{-10} m^2/s respectively. The effective diffusivities obtained for the second falling rate of original rice noodle at 60 °C and 90 °C are 7.59 x 10^{-11} m^2/s and 1.18 x 10^{-10} m^2/s respectively. These values fall within the range of noodles reported by other researchers (Kongkiattisak & Songsermpong 2012; Inazu & Iwasaki 2000).

2. The effective diffusivities resulted for the first falling rate of non-oil coated and original rice noodle subjected to heat pump drying at 38 °C are 7.75 x 10^{-11} m^2/s, and 5.59 x 10^{-11} m^2/s respectively. The effective diffusivities obtained for the second falling rate at 38 °C for non-oil coated and original rice noodle at 38 °C were respectively at 2.431 x 10^{-11} m^2/s. The effective diffusivities obtained for the first falling rate period of respective non-oil coated and original noodle are 1.14 x 10^{-10} m^2/s, and 1.05 x 10^{-10} m^2/s respectively. The effective diffusivities obtained for the second falling rate at 50 °C give straight lines for the non-oil coated and original rice noodle were respectively at 9.575 x 10^{-11} m^2/s and 8.78x 10^{-11} m^2/s.

3. Pre-treatment introduced in the drying process slightly reduced the drying time to record higher value of effective diffusivities. In regards of quality analysis, pre-treatment recorded better quality attributes in terms of hardness, total colour change, rehydration ratio, fat content, and sensory evaluation.

4. The quality analysis of freeze dried rice noodle reveals that it is superior in many quality aspects for example more stable texture, low starch gelatinization which leads to high rehydration ratio within 6 minutes, low total colour change, high porosity which leads to high full rehydration ratio. The freeze dried sample scored very well in sensory evaluation test. However, the high porosity in freeze dried sample may somehow cause severe microbial growth subjected to stability test. Therefore, freeze drying is not appropriate for long term storage only if properly sealed packaging is introduced like vacuum packaging. The occurrence may only be absent with the condition that oxygen concentration must be very low to have an effect (Hall 1988).

5. Heat pump drying on the other hand gave moderate scores in textural attributes, starch gelatinization which leads to good rehydration ratio within 4 minutes, moderate colour change, low porosity which does not support rapid rehydration but gave moderate rehydration ratio within 7.5 minutes. It gave restricted shrinkage pores to permit further oxidation to occur.

6. Rice noodle subjected to heat pump drying at 38 °C with pre-treatment is the best drying method in order to preserve the best quality attributes with comparable drying time. Thus, it is the best solution for merely normal packaging to guarantee longer shelf life.

5.2 RECOMMENDATIONS

This study has provided important information on the effects of introducing different drying methods for rice noodle in order to preserve the quality of the dried noodle. However, further improvements may be essential to the rice noodle market for future studies.

These are the followings suggestions:

1. The results from this study had shown that heat pump drying process had a special feature where it could dry the rice noodle under low temperature with low humidity in the shorter duration. Thus, by designing the control of relative humidity and air velocity, these could improve the efficiency of heat pump drying in rice noodle.

2. The transparency phenomenon of rice noodle has been well observed whereby the transparent noodle recorded satisfactory preliminary shelf life results by deducing from the effects of stability test resulting to microbial growth. Therefore, it may be investigated further by learning deeply the effect of the phenomenon in the studies of storage stability and heat stability in regards of its shelf life.

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