UNIVERSITI PUTRA MALAYSIA

METHYLCELLULOSE COATING TO REDUCE OIL UPTAKE IN FRIED POTATOES

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Sincerely,

Lua Hwee Ying

ABSTRACT

The performance of methylcellulose with different concentration to produce low oil content in deep fried potato strip was studied by the relation of the cellulose behaviour and the coating formulations of Methylcellulose. The rheology behaviour of Methylcellulose showed the gelation time based on temperature difference of 1.0wt% Methylcellulose is the faster compared to others concentration. There is a strong relationship of the gelation time and the oil uptake of fried potatoes. After the frying process, the 1.0wt% Methylcellulose coating formulation showed the lowest oil uptake reduction and moisture loss are 25.21% and 75.64% respectively. On behave, the percentage of relative variation of oil reduction and water retention for 1.0wt% Methylcellulose are 44.38% and 57.89% compared to uncoated control sample. In fried potato strip, the moderate viscosity application which is 1.0wt% shows the best from the oil uptake during frying. The light microscope test was analysis the surface morphology of fried potatoes and image J analysis was done to measure the pore sizes to relate mass balance occurring during frying process. It was noticed that the pore size area of 1.0 wt% contributed to the smallest surface area of 10505 μm^2 which contribute to minimal mass balance between oil and water content inside the potato strip during the frying process. Thus, the formulation of 1.0 wt% of Methylcellulose concentration is recommended for minimizing the oil uptake during the deep frying process.

ABSTRAK

Kepekatan methlcellulose sebagai salutan memberi kebekesanan untuk meningkatkan prestasi pengambilan lemak dalam teknik mengoreng kentang secara convensional. Dalam penyelidikan ini akan fokus untuk mencari formulasi methlcellulose yang terbaik mengikuti kajian rheologi yang dibezakan oleh kepekatannya sehubungan dengan jumlah pengambilan lemak dalam kentang goreng. Mengikuti hasil kajian, kepekatan methlcellulose 1.0wt% merupakan formulasi yang terbagus dimana mehtlcellulose hanya memerlukan masa yang pendek untuk berlaku gelation proses. Sehubungan dengan itu, jumlah pangambilan lemak semasa teknik mengoreng secara convensional bagi methlcellulose 1.0wt% adalah hanya 44.37%, manakala pengekalan air ialah 57.89% berbanding dengan sampel yang tidak disalut dengan Methlcellulose. Selain itu, kelikatan methlcellulose juga membawa impact kepada keberkesanan salutan kepada sampel tersebut. Salutan yang tebal ataupun nipis akan menyebabkan berlakunya ketidakberkesanan dalam jumlah pengambilan lemak. Dengan itu, 1.0wt% menunjukkan kelikatan yang paling sesuai untuk menjadi salutan pada kentang. Ujian mikroskopi cahaya telah dijalankan untuk memerhati morfologi permukaan dan menentukkan kebesaran liang yang terdapat di permukaan menggunakkan perisian image j. Melalui kajian, sampel dengan salutan methlcellulose 1.0wt% menunjukkan kawasan permukaan yang terkecil berbanding dengan sampel yang lain. Hal demikian, jisim imbangan teknik boleh dibincangkan mengunakkan liang yang terhasil dengan jumlah pengambilan lemak dan penguapan air semasa teknik mengoreng convensional dijalani.

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CHAPTER 1

INTRODUCTION

1.0 Overview

Deep-fat fried products are globally appreciated to prepare tasty foods quickly, which enhance the flavour, texture and appearance of food products. In addition, worldwide fast food companies serve literally tons of deep-fat fried foods such as French fries, fried chicken, nuggets, onion rings, etc. Besides, health and sensory aspects should be stress on to meet consumer demand in deep-fat fried products.

One of the main problems associated with fried food is its high oil content. Some fried products may contain fat up to 50% of the total weight (Pinthus, Weinberg & Saguy, 1993). For example, lipid content of French fries increases from 0.2 to 14%, lipid content may reach 40% in potato chips; raw fish with 1.4% reach 18% fat after frying (Smith, Clifford, Creveling & Hamlin, 1985; Mackinson, Greenfield, Wong & Willis, 1987). Thus, oil uptake in fried foods has become a health concern. Different ingredients have been proven to be effective in reducing the amount of oil absorbed by fried food. The simplest and the most convenient method to reduce the oil content that does not require variation in equipment design is the use of additives by adding hydrocolloids.

Hydrocolloids are the most widely investigated biopolymer in the field of edible coating to improve coating performance especially in food and beverage products. Addition of food hydrocolloids as dry ingredients is a practical way for improving barrier properties, yield and strength (Meyers, 1990). Typically, their functions as thickening and gelling agents due to the thermal-reversible properties in hydrocolloids.

Specifically, the hydrocolloid coatings are often known to reduce the oil uptake of fried foods. Several hydrocolloids like proteins and carbohydrate, have been tested to reduce oil and water migration (Debeaufort & Voilley, 1997). Williams and Mittal (1999) found that methylcellulose (MC) films reduced fat uptake more than hydroxypropylcellulose and gellan gum films applied to a pastry mix.

Cellulose derivatives, including hydroxypropyl cellulose (HPC), hydroxypropylmethylcellulose (HPMC) and methylcellulose (MC) are most useful hydrocolloids (Albert & Mittal, 2002). All these cellulose derivatives are water-soluble polymers with good film-forming properties and the hydrophility increases in the order HPC<MC<HPMC< CMC.

Edible coatings on the surface of the foods can be directly consumed with the food are in the service of modern food preserving systems given the changes in the lifestyle of consumers. Thus, various hydrocolloids have been tested as an oil barrier coating material. Mallikarjunan, Chinnan, Balasubramaniam and Phillips (1997) working with mashed potato balls reported a reduction, compared to uncoated balls, with 14.9, 21.9 and 31.1% in moisture loss and in 59.0, 61.4 and 83.6% in fat uptake for samples coated with corn zein, hydroxypropylmethylcellulose(HPMC) and methylcellulose (MC) films, respectively.

In previous study, different cellulose derivatives were tested in coating formulations to reduce oil uptake of fried products. García, Ferrero, Bértola, Martino, & Zaritzky (2002) stated that the most effective formulation of coating for potato strip is 1% MC and 0.5% sorbitol with 40.6% oil uptake reduction and 6.3% increase in water content. Since oil barrier properties of the coating depend on the formation of a uniform layer, plasticizer incorporation is necessary to obtain a flexible coating without cracks.

1.2. Potato

There are about 5000 potato varieties with great different in size, shape, colour, texture, cooking characteristics and taste. In this project, the sample of food used is Russet potato. Russet potato is rich in micronutrient such as vitamins, minerals, colorants and antioxidant phenols.

Potato generally is lower in fat, but is the preparation and serving method with high fat ingredients, for example deep fat frying French fried that raises the caloric value of the food. For common French fried, high absorption of oil and significantly reduce mineral and ascorbic acid content become health concern recently. Based on Aguilera and Gloria-Hernandez, research, fried potatoes contain a significant amount of oil at the end of deep frying. There is ~35% of oil by weight for potato chips and ~15% by weight in French fried.

Table1. 1: Typical chemical composition of the potato tuber

Compositions	Percentage (%)
Water	72-75
Starch	16-20
Protein	1-2.5
Fibre	1-1.8
Fatty acids	0.15

Source: "The Potato" International Year of potato 2008

1.3. Problem statements

The conventional deep frying process has caused significant oil uptake to the fried foods. Thermal reversible properties of edible coatings affect the heat transfer on the food matrix in frying condition. In high temperature, hydrophobic saccharides become less soluble, there will be a tendency for surface minimization by surfaces interacting and excluding water. Therefore, this study was to determine the relationship between the thermal reversible mechanism of methylcellulose and the oil uptake during deep-fat frying.

1.4. Research objectives

The aims of this study are to study the effect of coating formulation based on the hydrocolloid (methylcellulose) for reducing the oil uptake during frying in potato strips and to characterize the properties of methylcellulose in term of the thermal reversible gelation mechanism.

1.5. Scope of work

In this study, the focus is given on the, methylcellulose which belongs to gelling and thickening agent was chosen as coating materials. Potato strips were coated with hydrocolloid solutions at 4 different concentrations (0.5%, 1.0%, 1.5%, and 2.0%) and undergo deep-fat frying at 180°C±10 °C. The methylcellulose solutions were analysed in term of the thermal reversible gelation at varies temperature and shear rate with different concentrations. Moisture content and lipid content test was run to determine the relationship of the moisture content and lipid content in deep-fat frying process.

1.6. Thesis structure

This thesis is separate into five chapters including an introduction, literature review, methodology, results and discussion and lastly the conclusion and recommendation for future works. Chapter 1 discussed an overview of hydrocolloid coating and frying process, problem statements and objective of the project. Chapter 2 summarizes the studies of methylcellulose in food application and frying process. The hydrocolloid coatings, reversible thermal gelation properties, factors affecting the oil absorption, mechanism of oil uptake and water retention and crust formation were summarized in this chapter. The materials and equipment used were detailed up in chapter 3 as well as the sample preparation and experimental works. Following is chapter 4 which includes the preliminary result and discussion of the properties of MC solution based on reversible thermal properties and effect of the coating to the fried potato in deep fat frying. Lastly, chapter 5 concludes the thesis and recommended the possible future works to investigate the application of MC coating in fried potato strips.

CHAPTER 2

LITERATURE REVIEW

2.0. Common practice in deep fried potato strips

Fried potato strips are commonly called French fries are widely consumed around the world due to its unique texture, flavour and appearance. Deep-fat frying process is a dehydration process that requires rapid heat and mass transfer, exchange inside the food product when immersed in hot oil. However, awareness of the health impact of consuming a high fat diet is becoming a concern for consumers and processors around the world (Adedeji & Ngadi, 2009).

Traditionally, the process of French fries includes a pre-frying step in industrial production. The objectives of this step are to coagulate the batter around the food and contribute to the development of colour and partially inhibit dehydration during the freezing step (Sanz, Salvador, & Fiszman, 2004). Section 2.1.1 described the process flow of fried potato strips with pre-frying treatment (Keijbets, 2001). Several factors have been reported to affect oil absorption in fried potatoes. These include oil quality and composition, frying temperature and time, product composition, and the coating applied on the surface of the product (Kim, Lim, Bae, Lee, & Lee, 2011; Moreno, Brown, & Bouchon, 2010; Rimac-Brnčić, Lelas, Rade, & Šimundić, 2004)

2.0.1. Process flow diagram of pre-fried potato strips

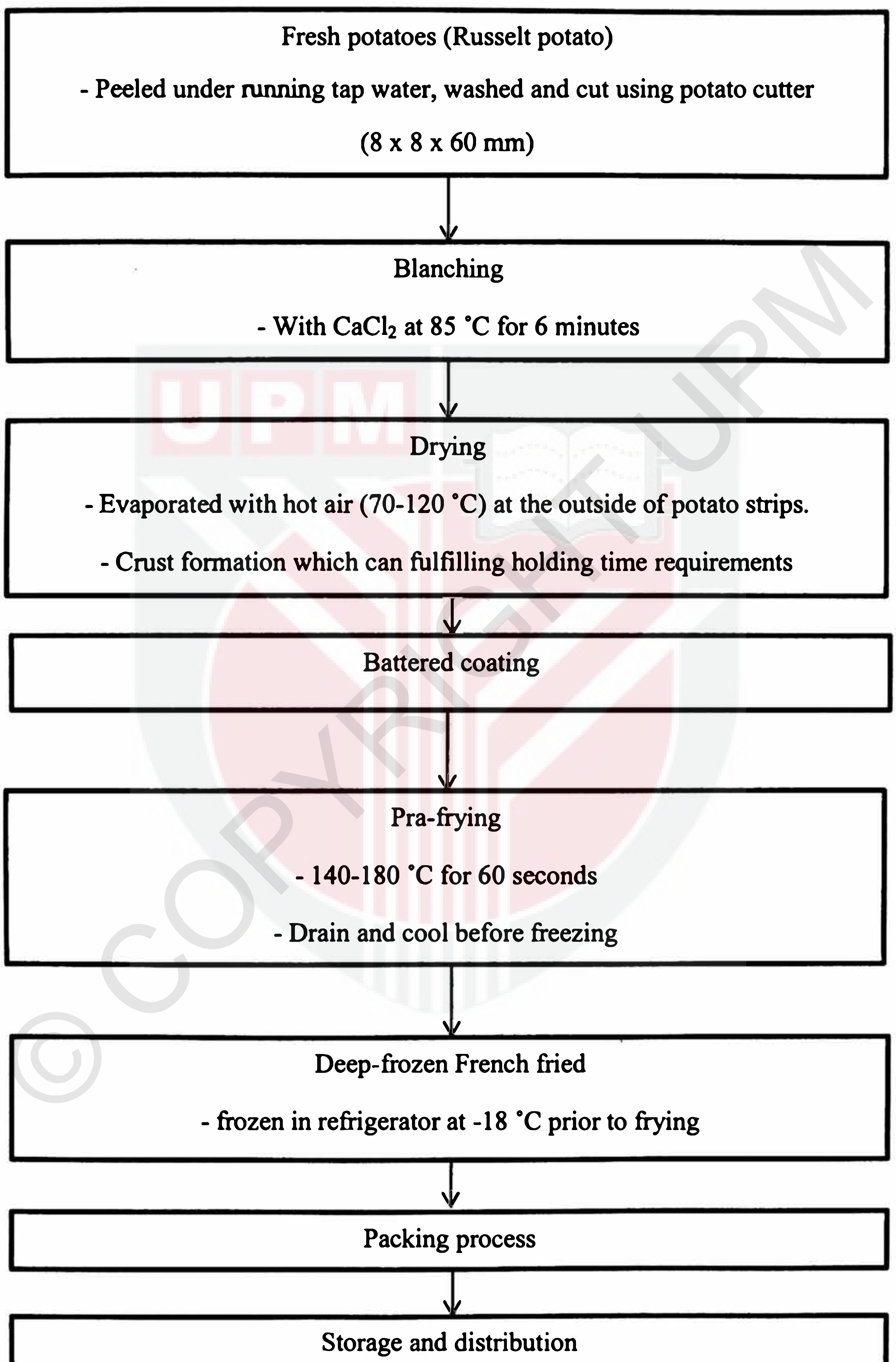


Figure 2. 1: Process flow of manufacture of pre-fried French fries

2.2. Hydrocolloid for oil uptake reduction

Hydrocolloids or gums are diverse group of long chain polymers characterized by their property of forming viscous dispersion and/ or gels when dispersed in water. An occurrence of a large number of hydroxyl groups noticeably increases their affinity for binding water molecules rendering them hydrophilic compounds. Hydrocolloids play a leading role and major reduction claims in the literature using various types of polymers (Mellema, 2003).

Hydrocolloids are beneficial in many fields such as agriculture, food, cosmetic, paper, textile, pharmaceutical, among many others. Hydrocolloids are high molecular weight, which can used to produce solutions or highly viscosity suspension or gels with low dry-substances content (Phillips, 2004). In food, hydrocolloids have extensive functional properties including; thickening, gelling, emulsifying, stabilization and coating. The primary reason behind the ample use of hydrocolloids in foods is their ability to modify the rheology of food systems.

For fried product, there are two main ways of applying hydrocolloid which are edible coating or edible film that produces from edible biopolymers and food-grade additives. Basically, the film-forming biopolymers can be proteins, polysaccharide (carbohydrates and gums) or lipids (Han & Gennadios, 2005).

Figure 2. 2: Edible film made from carboxymethyl cellulose

The uses of edible films and coatings are to extend the shelf life of meat and to improve the quality of fresh, frozen and manufactured food items. Besides, coating preserves and enhances food quality as some edible coatings, especially hydrophilic polymers are a good barrier to fats and oils (Varela & Fiszman, 2011). Edible coating was applied between the food component and its surface was believe hinder absorption of oils, resist the moisture content and improving its nutritional qualities (Mallikarjunan, Chinnan, Balasubramaniam, & Phillips, 1997). This application has become commonly used in recent years, as oil uptake in fried products has become a health concern which related to obesity and coronary disease (Gustavo F. Gutiérrez-Lopez, Jorge Welti-Chanes, 2008).

Edible films can be classified into hydrocolloids, lipids and composite films depend on the nature of their components. For hydrocolloids, there are various popular polysaccharides and cellulose derivatives such as Methylcellulose (MC), Carboxymethyl cellulose (CMC) and Hydroxypropyl cellulose (HPC) were being used in studying to reduce oil absorption (Garmakhany et al., 2008; Huse et al., 1998; Pahade & Sakhale, 2012). For the recent study, MC and HPMC used in formulations were succeeding in an oil uptake reduction in deep-fat frying of potato strips and dough disc (García et al., 2002).

Figure 2. 3: Micrographs of fried fried dough dics coated with 1% methylcellulose

Moreover, protective layer on the surface of the samples were formed by cellulose derivative coating during the initial frying stage. This is formed due to the thermal gelation properties of cellulose derivative that induced gelation when temperature achieve 60°C and above based on the nature of their components. Refer to the study, Mallikarjunan et al. (1997) state that the protective layer was functional to retard the transfer of moisture and fat between the sample and the frying medium. An assumption can be made that the protective layer formed where the hydrophilic side of cellulose derivatives attached to the sample and high temperature applied to induce gelation. From here, natural barrier for moisture content loss during frying process.

The summary of edible coating application in deep fat frying process was illustrated in Table 2.1. Table 2.1 shows the types of coating, sizes and types of samples, frying conditions and the reduction of oil uptake based on the study.

Table 2. 1: Application of edible coatings in deep-fat fried products.

Coatings	Plasticizer	Size	Samples	Frying condition	Reduction in oil uptake (%)	References
Methylcellulose (MC)	PEG	47 mm diameter	Potato balls	175 °C 240 sec	59	Mallikarjunan et al., 1997
	Sorbitol	(0.7x0.7x5 (cm)	Potato strips	180±0.5 °C 4 min 1:6	35-40	Garcia et al., 2004
	No	8 x 8 x 60 (mm)	Potato strips	strips: oil ratio 180±2 ∘ C 2 min	29.5	Pahade & Sakhale, 2012
	Glycerol	0.18 ± 0.02 cm 3.5 cm diameter	Potato chips	150±0.5 °C 3 min	30	Tavera-Quiroz et al., 2012
	Sorbitol	3.7cm -diameter 0.3cm - high	Dough disc	180±0.5 °C 4 min 1:6	35-40	Garcia et al., 2004

Carboxymethyl cellulose (CMC)	No No Glycerol No	6 × 1 × 1 (*cm*) 8x8x60 (mm) NA 0.7x0.7x0.7 (cm)	Potato Potato strips Potato pellet chips Potato slices	175°C 2.5 min 180 ± 10 °C 6 min 180±2 °C 10 seconds 180 °C 3 min	30.3 54 49.9 70-76	Daraei Garmakhany et al., 2014 Rimac-Brncic et al., 2004 Angor, 2016 Daraei Garmakhany et al., 2008
Hydroxypropyl cellulose(HPC)	PEG PEG No	47 mm diameter 36.4 mm diameter 8 x 8 x 60 (mm)	Potato balls Akara Potato strips	175 °C 240 sec 166°C 1:6 strips: oil ratio	61.4 37 47	Mallikarjunan et al., 1997 Huse et al., 1998 Pahade & Sakhale, 2012
Gellan gum	No No	NA 1x1x4 (cm)	Pastry dough Potato strip	10 min 170° C 100 sec	55 12.2	Albert and Mittal, 2002 Kim, Lim, Bae, Lee, & Lee, 2011

*PEG-polyethylene glycol

2.3. Methylcellulose (MC)

Based on environmentally safe and biodegradable natural polymers, there has been increased interest in self- associated polymer systems recently. These compounds include methyl cellulose (MC), hydroxypropyl cellulose (HPC), hydroxypropyl methyl cellulose (HPMC), and methyl ethyl cellulose (MEC). These cellulose ethers are widely used as a gel-forming agents and thickeners in the food industry due to the physically thermo-reversible gel properties in aqueous solutions. Among the cellulose compounds mentioned, the most widely used is MC.

Pure MC is produced from alkali cellulose by a reaction with gaseous or liquid methyl chloride. In side reactions the methyl chloride is hydrolysed to form methanol, and subsequently the methanol is etherified by methyl chloride, forming dimethyl ether (Thormann, Bodvik, Karlson, & Claesson, 2014).

Cell-OH.NaOH+ClCH3 (gaseous/liquid phase)⟶ Cell-O-CH3+NaCl+H2O

The reactions take place between 70 and 120°C. Methylation is an exothermic reaction, the activation energy being 80kJ/mol.

MC has been widely used in many industrial applications, especially in food application (García et al., 2004; Huse et al., 1998; Kurek, Ščetar, & Galić, 2017; Tavera-Quiroz, Urriza, Pinotti, & Bertola, 2012). MC is the simplest cellulose derivative, where methyl groups (–CH3) substitute the hydroxyls at C-2, C-3 and/or C-6 positions of anhydro-D-glucose units (Nasatto et al., 2015). The molecular structure of methylcellulose is as shown in Figure 2.4.

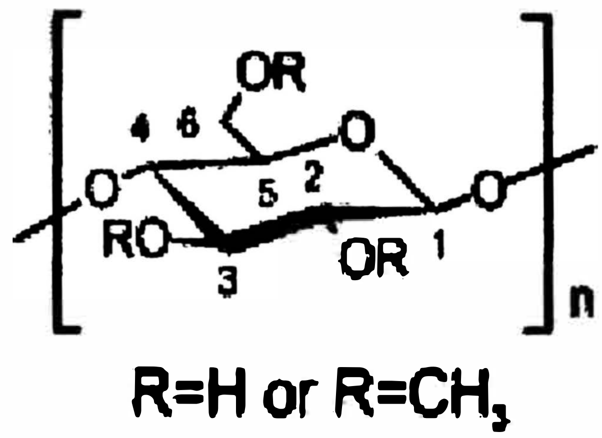


Figure 2. 4: Repeating unit of molecular structure for methylcellulose (MC)

Normally, the grades of MC have a degree of substitution of varying from 0 to 3. MC exhibit good water solubility at room temperature with a degree of substitution of around 1. The water solubility was directly proportional to the degree of substitution. However, it decreases again with further methylation and changes to solubility in organic solvents at a DS of approximately 2.6 and above, because the material becomes increasingly hydrophobic (Thormann et al., 2014).

In this study, MC was selected to apply as an edible hydrocolloid coating for the potato strips in deep fat frying. Major reduction in oil uptake by applying MC as the coating was claimed in the literature study. According to Garcia (2004), 35-40% of oil reduction with the most efficient formulations 1% MC and 0.5% sorbitol for fried potatoes. The structure of MC gels and the structure property relations were studied to ensure MC has the ability of the formation a gel layer at various temperature (Chatterjee et al., 2012).

2.4. Mechanism of gelation properties

Methylcellulose (MC) is a natural polymer which is widely used for industrial purpose due to the peculiar properties. MC has the unusual property of forming gels on heating and reverting to the solution state on cooling; called thermo-reversible gelation properties. This property attributed to hydrophobic interaction which involving highly substituted units.

Commercial methylcellulose (MC) is hydrophobically modified cellulose in heterogeneous polymers form. MC consisting of highly substituted zones called "hydrophobic zones" and less substituted ones called "hydrophilic zones". The evolution of viscosity and turbidity of MC solutions during heating and cooling cycles in a small polymer concentration range (10–25 g/l) are reported in the literature by experimental work (Desbrières, Hirrien, & Ross-Murphy, 2000).

Thermogelation of methylcellulose was studied in relation to the molar mass and concentration in aqueous solution. Recent work had brought interest results on edible coating of fried food from Sanz (2005) the temperature resulted in a transition from a soft gel at 15 °C (behaviour in the innovative process before the coagulation step) to a stronger although still soft gel at 60 °C (behaviour after the coagulation in hot water). The postulated structures and processes involved in the thermogelation of Methocel are shown in Figure 2.7.

Gelation properties in MC are affected by hydrophobic effect units which is available in polymers. Figure 2.5 illustrated the mechanism of MC gelation by heating. Literature reproduced with permission from American Chemical Society (2001) state that during heating, the gel is formed by the hydrophobic junction consisting of hydrophobic effective units and the mean length M_e between two junctions remains constant when the gelling temperature are higher than 42.5°C.

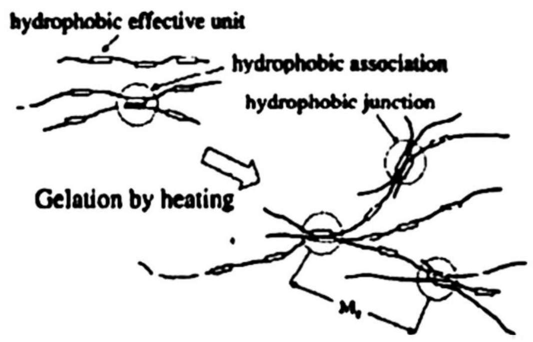


Figure 2. 5: Schematic drawing showing gelation through the hydrophobic effective units of methylcellulose. (Literature reproduced with permission from American Chemical Society ,2001)

On the other hands, the study concluded better method provides faster dissolution of the particle in a homogeneous solution by dissolution rate (Nasatto et al., 2015). Influence of temperature and molecular weight for 10g/L aqueous solutions observed between 10 to 75°C shown in Figure 2.6.

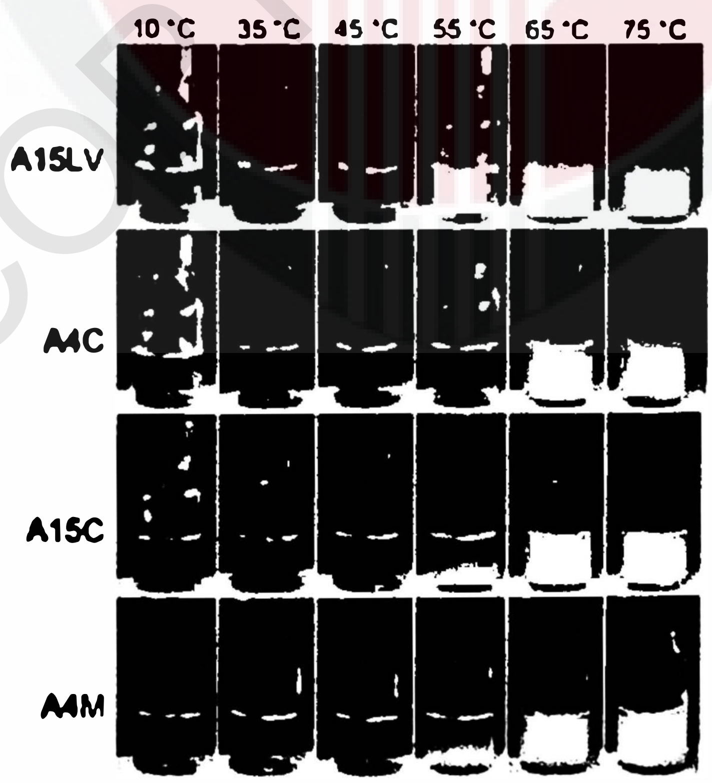


Figure 2. 6: Influence of temperature and molecular weight for 10g/L aqueous solutions observed between 10 to 75°C. (Nasatto et al., 2015)

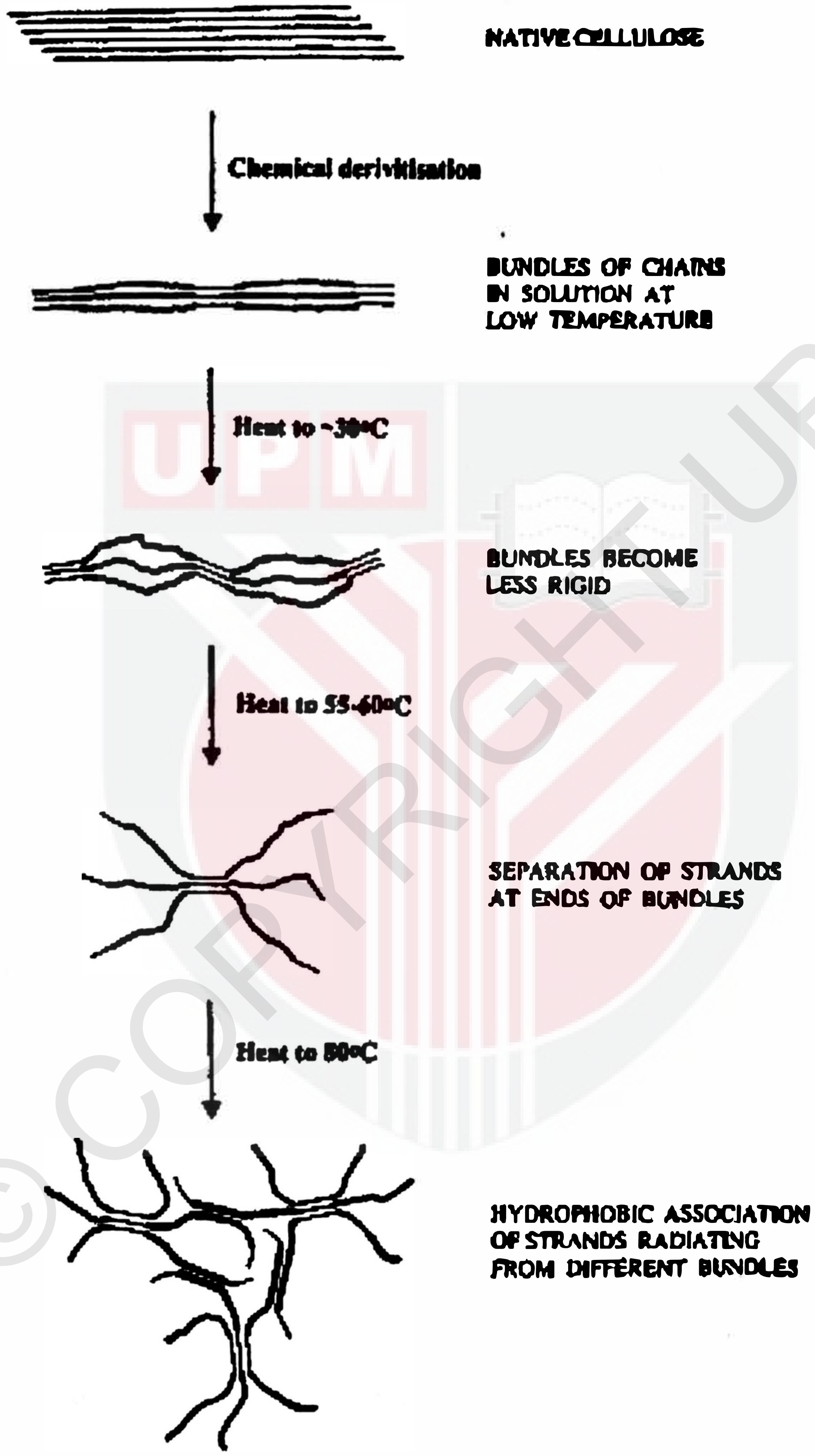


Figure 2. 7: Schematic illustration of the postulated structures and processes involved in the thermogelation of Methocel. (Sanz, 2005)

2.5. Pre-treatment process

Pre-treatment have been widely used in reducing the oil absorption before and after frying. Pre-frying treatment is one of the approaches to reduce oil absorption by reducing the surface permeability. There are two approaches of pre-frying treatment will be discussed in section 2.5.1 and 2.5.2.

2.5.1. Blanching

Blanching is a mild heat treatment where food is heated rapidly to a predetermined temperature, holding for a specified time, either then cooling rapidly or passing immediately to the next processing stage (S. Grandison, 2012). There are several blanching treatments for potato which are water blanching and $CaCl_2$ blanching.

Water blanching treatment for potato involved the immersion of potato strips in water at 50°C and above. There is greatest oil absorption for the potato blanched in water compared to potato blanched with 0.5% $CaCl_2$ following immersion in a 1 % solution of carboxymethyl cellulose (Rimac-Brnčić et al., 2004).

The functions of blanching treatment in potato are to reduce the starchy component in potato and activate pectinesterase enzyme before frying process. A study was reported that the enzyme was activated before frying may decrease the porosity and thus reduce the oil uptake (Aguilar et al, 1997). Furthermore, blanching has been reported to improve the colour and texture of the chips by reducing sugar content.

2.5.2. Drying

Drying is a controlled condition to remove the water by evaporation which involving the heat and mass transfer. The main purpose of drying is to lengthen the shelf life of foods by reduction of water activity. On the other hands, pre-drying is a pre-treatment process before frying to lower the initial moisture content of the potatoes. From research, the moisture content of the potatoes is typically constant of 60% wet in basis.

Heat supply through a current heated air over the foods was widely used to reduce the water activity and extend the shelf life of foods. Heat is transfer of air by convection and conduction was transferred within the food. During the pre - drying process, free water molecule available in the surface of the potatoes will evaporate. This condition may affect the frying process in term of crush formation, fries texture and oil uptake. According to Franco and Rommy (2008), a lower initial moisture content of potatoes is efficient to reduce the oil uptake during frying process.

Theoretically, pre-frying using drying treatment is not solely to reduce the initial moisture content of foods but also change the structure of the food which external crust forming with low permeability. This increased the resistance of oil absorption during the frying process, so reducing in oil uptake.

2.6. Frying process

Frying is a process of cooking and drying through contact with hot oil involving simultaneous heat and mass transfer. Frying process is selected for preparing foods with an attractive and tasty surface that improve overall palatability of foods. Frying can be considered a complex form of the Stefan class of problem. According to Stefan (1891), the presence of a moving interface which divides two regions of distinct physical and thermal properties which generalize from the Stefan heat transfer. Deep-fat frying is widely used method for frying process nowadays.

In deep-fat fried product, two aspects must be concern which is health and sensory to meet consumer demand. Deep fat frying involved the immersion of food in oil (fat) at a temperature above the boiling point of water with a common temperature ranged from 170°C to 190 °C (Moreno and Bouchon, 2008). This condition leads to high rates of heat transfer, rapid cooking, texture development and browning.

In addition, worldwide fast food companies serve literally tons of deep-fat fried foods such as French fries, fried chicken, nuggets, onion rings, etc. However, frying process is more complex due to the coupled heat and mass transfer, which separated by a moving boundary and temperature well above the boiling point of water in two distinct regions (Farkas, Singh, & Rumsey, 1996b). Figure 2.8 illustrates the heat and mass transfer during frying where convection and conduction of heat transfer occur.

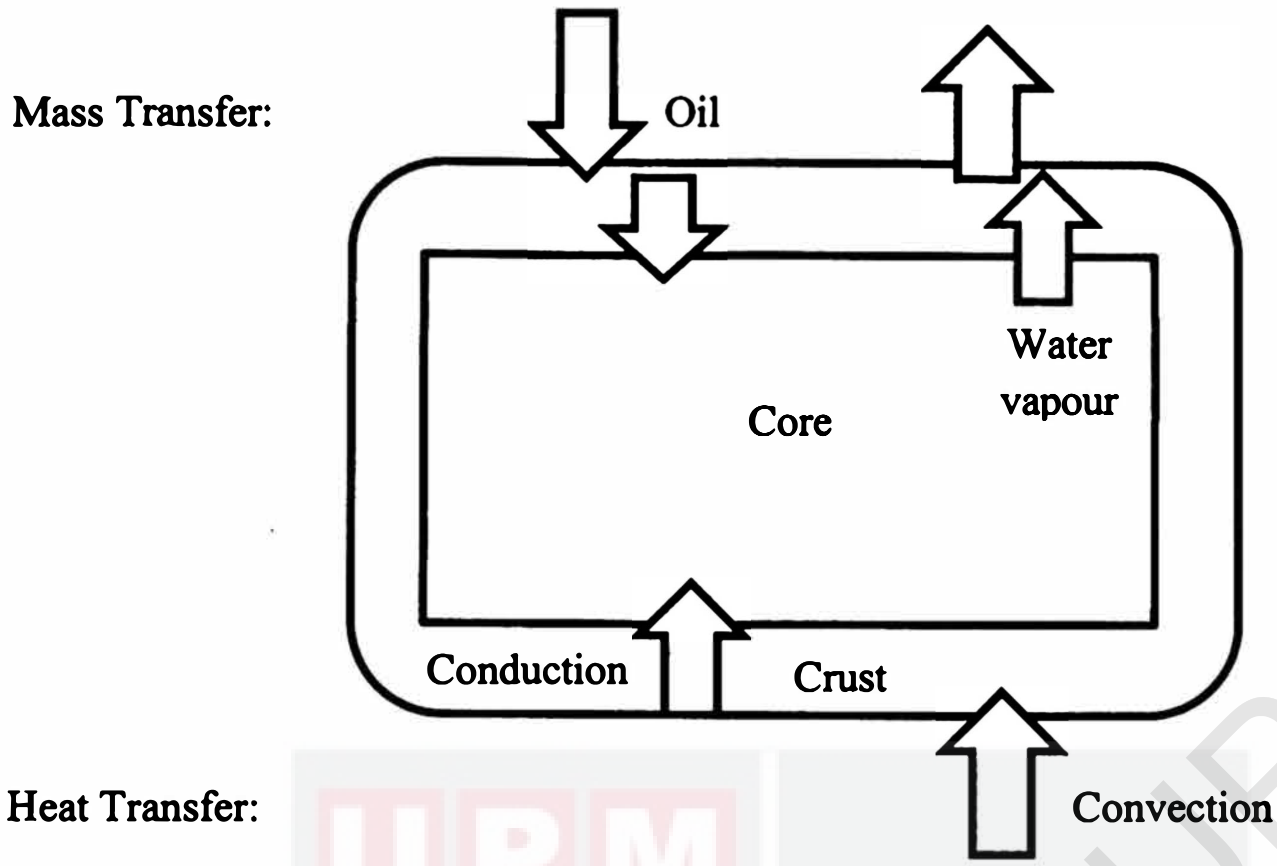


Figure 2. 8: Schematic diagram of simultaneous heat and mass transfer during frying

The frying process involves a series complex chemical and physical change. Chemical reactions in the form of surface pyrolization, gelation of starch, denaturation of protein, and flavour development take place. While, physical changes are present as a decrease in moisture content, increase in temperature and oil content, development and growth of a crust layer, and possibly shrinkage or swelling of the product as a whole(Farkas et al., 1996b; Farkas, Singh, & Rumsey, 1996a). Transformed coordinate system is shown in Figure 2.6 including core region, crust region and boundary region. A mathematical model of heat and moisture transfer in an infinite slab during frying was developed and solved by Farkas (1996). A study of physical damage when the product cut and cause the release of intercellular materials from the rough surface, starch gelation, protein denaturation, water vaporization, rapid dehydration of tissues and lead to oil uptake itself (Rimac-Brnčić et al., 2004).

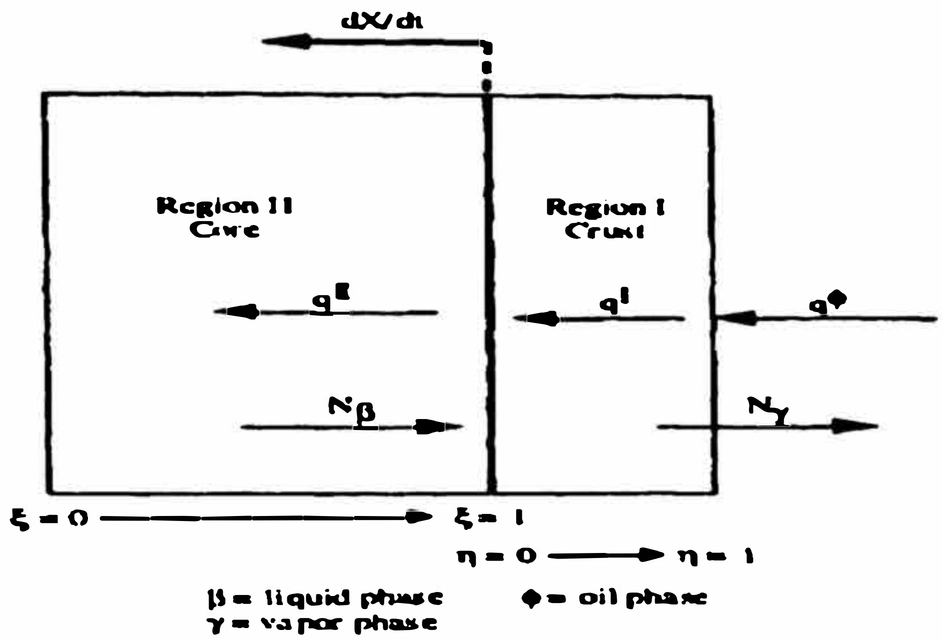


Figure 2. 9: Transformed coordinate system (Farkas et al. 1996b)

A typical French fries have a crispy of about 1-2mm, where most of the oil is located and a moist, soft centre, like a cooked potato and Millard reaction cause the changing colour of the crust formation. From the study, the temperature of the large piece of food like fried potato strip and meat ball will not rise above 100 °C. During frying process, explosive evaporation of vapour leads to formation of pores in larger sizes which allow oil absorption to take place (Mellema, 2003). The overall changes in deep fat frying was illustrated in Figure 2.9.

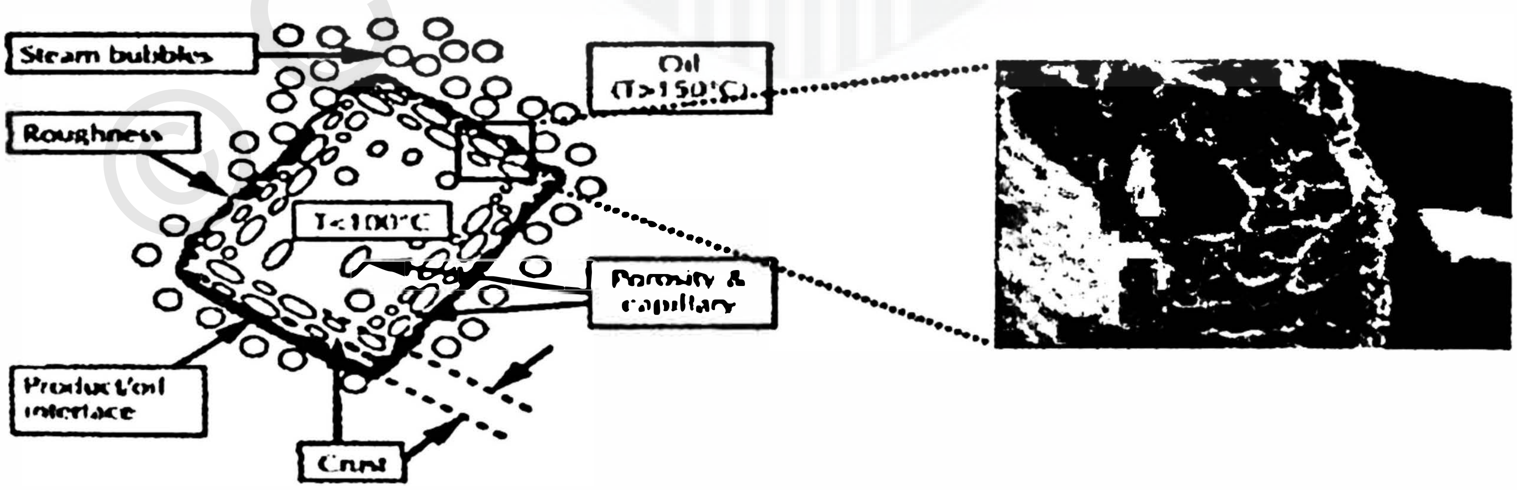


Figure 2. 10: Schematic cross section of a potato during deep fat frying (Left). SEM image of a cross-section of the crust of a fried potato (Right). (Mellema, 2003)

2.7. Mechanism of oil uptake

Oil absorption during frying process might be control through understanding the mechanism. Besides, condensation mechanism should be noted after frying process where it is probably most important for short frying times and large food samples. If longer times are used, the fat uptake is greater (O'Conner, Fisk, Sun, & Melton, 2000). Oil uptake is a dynamic, complex process and it might be controlled by understanding well the mechanism of oil uptake during frying process. Uftheil and Escher (1996) suggested that the oil uptake is a surface phenomenon involving the equilibrium between adhesion and drainage of oil upon the pieces remove from oil. Figure 2.10 shown the four basic situations occur during and after frying process.

Generally, the oil uptake phenomena explained by two possible mechanisms below (Mellema, 2003; Saguy & Dana, 2003):

I. Water Displacement

Evaporation of moisture vapour within the fried product through core and crust, creating pores in the cellular structure. During and after frying, several situations can be valid for the state of the pores affecting fat penetration. Water displacement creates a positive pressure pores by evaporation of water steam outward from core to surrounding and allow penetration of surface oil in fried food. Figure 2.11A shown the water displacement occurs during frying process.

II. Absorption during cooling phase

Condensation of water vapour occurs as the food temperature suddenly dropped. Consequently, internal pressure of the food decrease cause under pressure condition occurred in the pores of food. According to Mellema, 2003; Saguy & Dana (2003), "vacuum effect" occurred due to the condensation after frying process. The film layer of oil on the food surface will be driven into the pores and cause penetration of oil absorption into fried food. Figure 2.11 B is shown the condensation of steam cause "vacuum effect" after frying process.

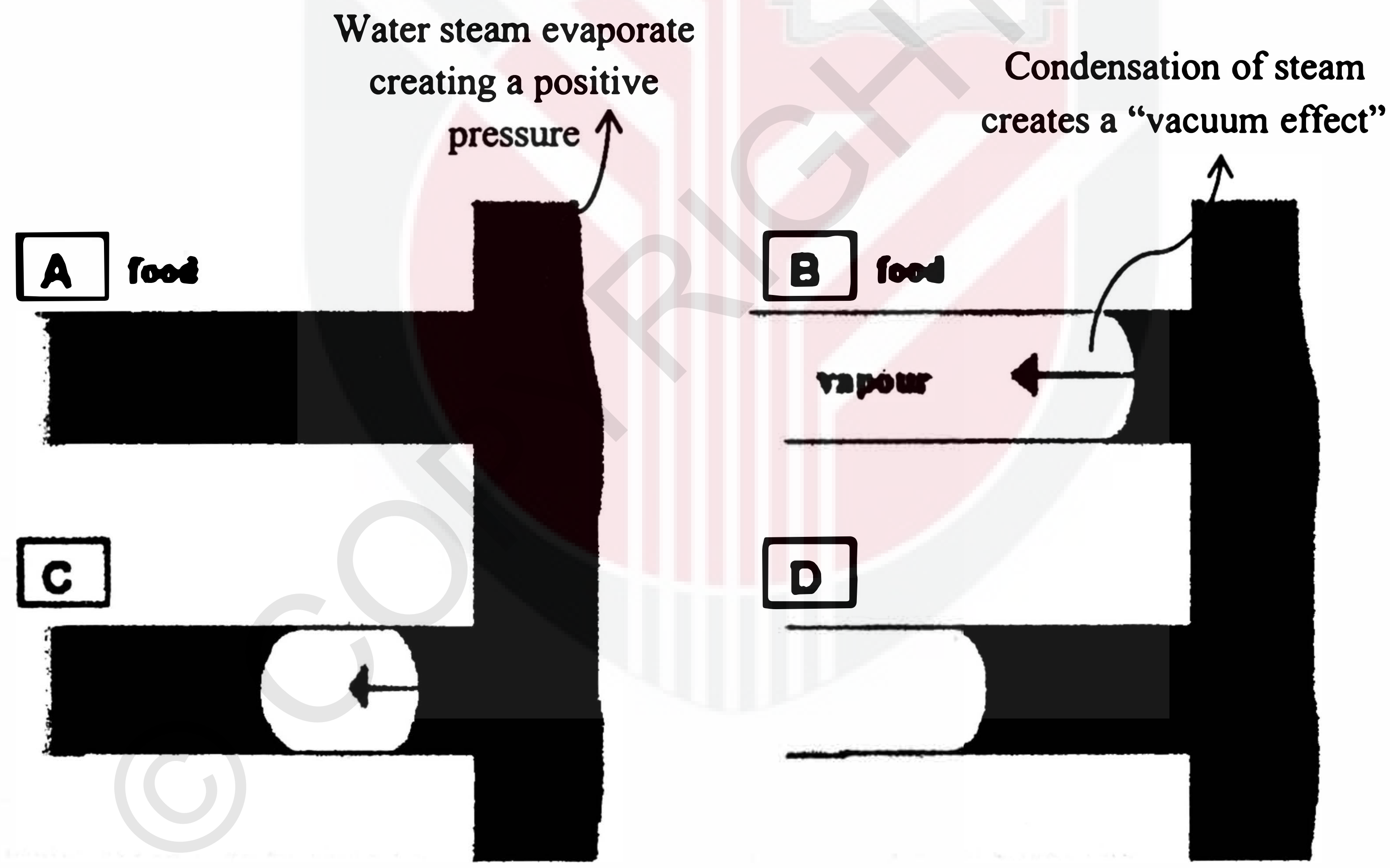


Figure 2. 11: Oil penetration into (a) water-filled pore, (b) vapour-filled pore or (c–d) combinations thereof. Wetting angle smaller than 90 can lead to oil penetration by the capillary mechanism. In the presence of vapour, oil penetration can also take place by the condensation mechanism (Mellema, 2003)

2.8. Crust formation

A layer with certain thickness of the tough outer surface of substances can define in term of crust. Crust formation happened due to evaporation at the product surface is fast compared with the moisture migration within the product. For a raw strip of potato, the outer layer is converted into a crisp crust where the core region remains moist and soft during frying (van Koerten, Schutyser, Somsen, & Boom, 2015).

Several researches have shown the relationship between the temperature and crust formation (Lioumbas, 2012). On the other hand, the determination of the crust formation is important due to the crust characteristics such as thickness and texture dictate the sensory perception of fried foods. According to Lioumbas et al. (2012), thicker crust part regarding on differences among the surface orientation due to fast heat transfer. Figure 2.12 shows the thickness of the crust in respect to gravity.

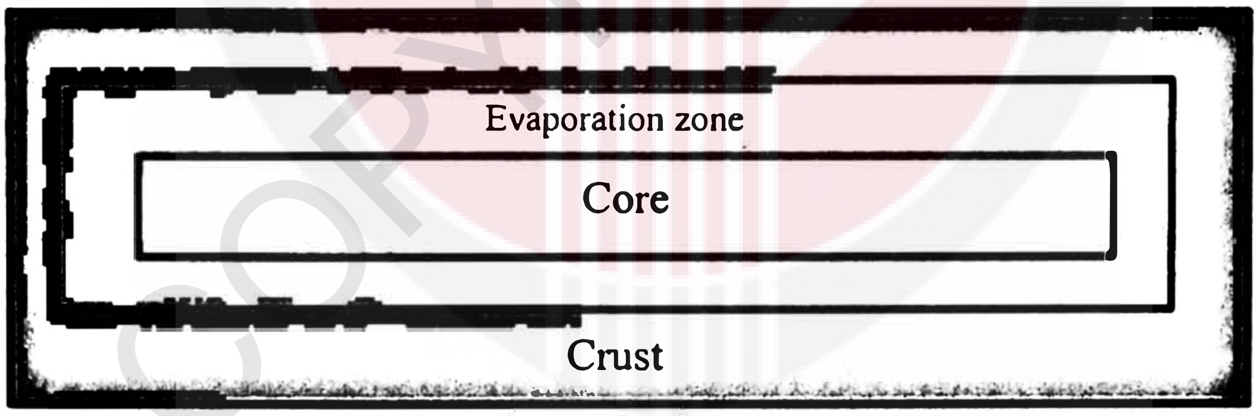


Figure 2. 12: A schematically depiction of the effect of potato surface orientation with respect to gravity on the thickness of the crust

High temperature of frying leads to the formation of water vapour due to pressure and concentration gradients, leaving behind pores that become significant in oil absorption. Moisture evaporation cause ruptures on the surface and generates voids, holes and crack on the crust formation. As the process continues, the large voids or holes created in the structure of the product could leads adhering of oil on the product's surface. (Rahimi, Ngadi, Agyare, & Koehler, 2017)

Based on Eleni et al. (2013), a study of systematic approach to measure the pore size in French-fried crust was done to comprehension and modelling heat and mass transfer within the potato, the mechanisms, the phenomena relating and the oil absorption. On the other hand, the structure and composition of product previous to frying seem to be a factor affecting the microstructure of fried food crust.

Figure 2.13 shows the micrographs of the surface and crust of fully fried potato by analysis of the SEM. According to the study, the existence of a bigger dimension of pores at the crust related to the pressure increase in the crust region during intense moisture removal. The behaviour of the crust porous relating to the capillary penetration theory of oil uptake has been developed by estimating the approximate rate of frying oil uptake in the crust region.

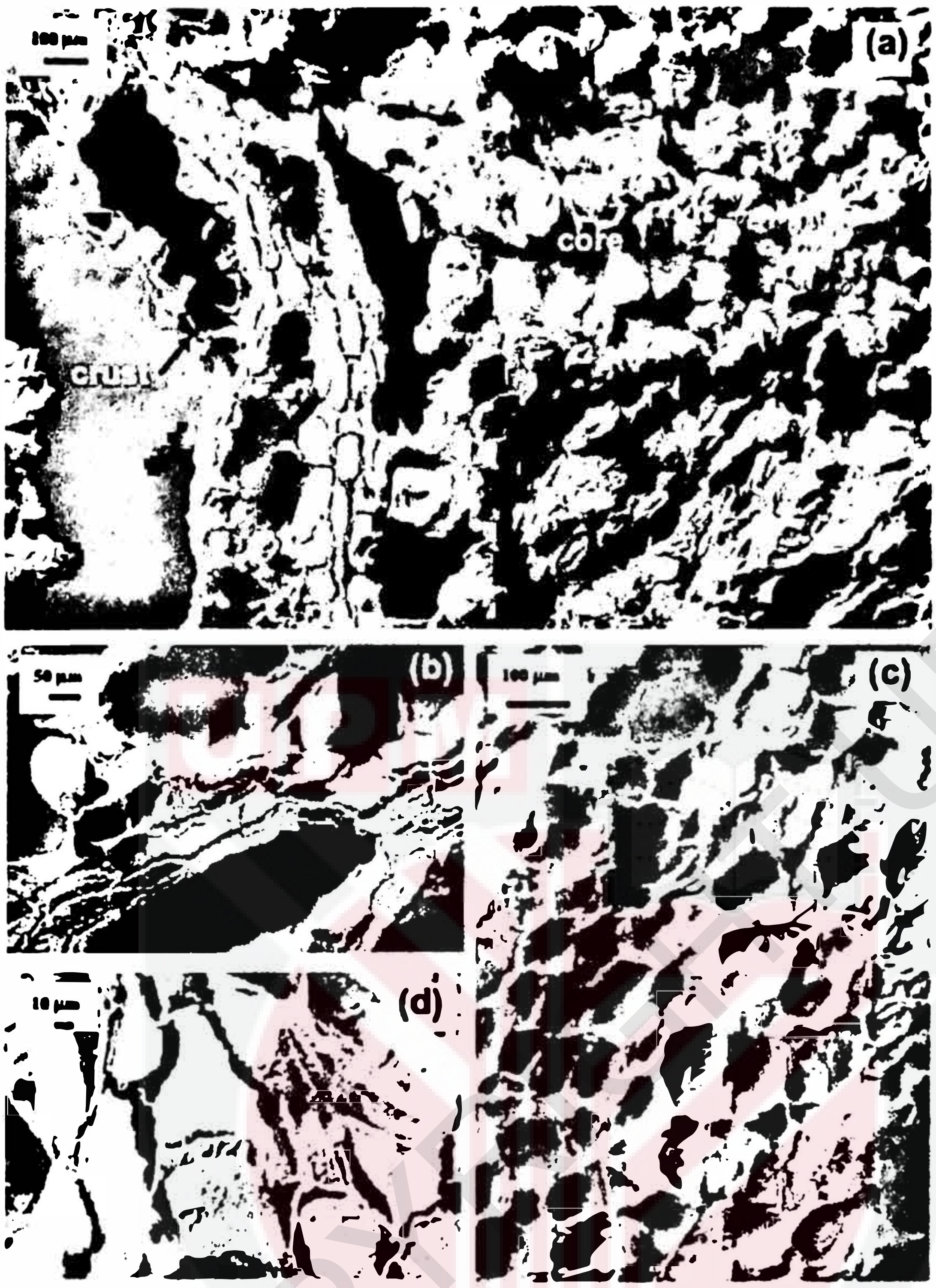


Figure 2.13: A schematically micrographs of the surface and crust of fully fried potato by analysis of the SEM. (a) Potato crust and core, (b and d) details of the crust and (c) surface of potato.(Eleni et al., 2013)

2.9. Summary

Hydrophobic edible coating, methylcellulose (MC) is significantly affected the moisture loss and oil absorption during frying process due to the peculiar properties. Thermogelation properties of MC take place in frying process where high temperature applied and formed a barrier for moisture loss. Gelation of MC will take place the pores or void formed by water evaporation during frying. Therefore, the degree of oil uptake reduced due to gelation properties. On the other hands, frying conditions may significantly affect the degree of oil uptake, such as frying temperature, frying methods and time for frying process. Consequently, an essential understanding of oil uptake mechanism is necessary in order to control the fat uptake in fried product.

CHAPTER 3

METHODOLOGY

3.0. Introduction

This chapter describes the materials and methods used in conducting experimental work. Section 3.2 describes the experimental design of this study. Section 3.3 describes the materials used in this experiment. Section 3.4 and section 3.5 discuss the detailed procedure in preparing the methylcellulose sample and potato strips sample. On the other hand, the frying method and conditions were described in section 3.6. Lastly, section 3.7 detailed the analytical method for methylcellulose solution and fried potato sample according to the objectives.

3.2. Experimental design

This study consists of 2 major parts which include (i) characterize the properties of methylcellulose in term of the thermal reversible gelation mechanism, (ii) determine the effect of coating formulation based on the hydrocolloid (methylcellulose) for reducing the oil uptake during frying in potato strips.

In the first part, the methylcellulose solution was prepared at different concentration to include 0.5, 1.0, 1.5, and 2.0 w/v%. Rheology test carried out to characterize the properties of methylcellulose where the gelation point of temperature can be determined for different concentration of methylcellulose. Besides, the frequency test was carried out to investigate the flow properties of methylcellulose with different concentrations.

In the second part, there is application of methylcellulose as an edible coating to fried potato. The effect of coating formulation applied to the samples includes the control sample and coated samples (0.5, 1.0, 1.5, and 2.0 w/v% of MC solutions). The types of analytical methods used in the identification of the effect include moisture content and lipid content. The result of moisture content compared with the lipid content in fried potato.

The summary of the experimental design is shown in Figure 3.1.

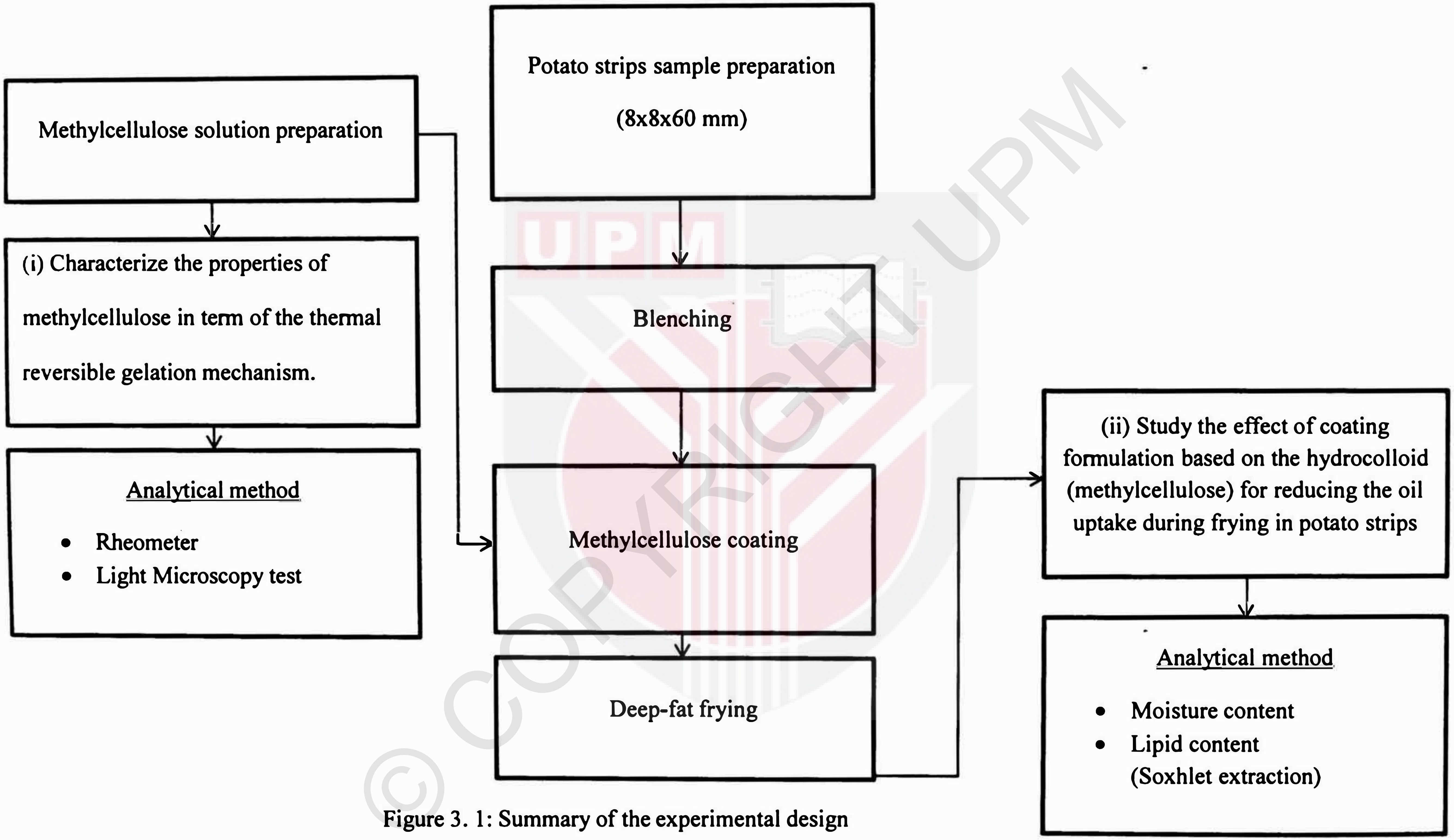


Figure 3. 1: Summary of the experimental design

3.3. Materials

Commercial sample of Methylcellulose, MC was provided by Shinetsu Chemical Co. Ltd., Japan. According to the manufacturer, the methylcellulose has an average degree of substitution (DS) of 1.8 and a weight-average molecular weight of 310 000 determined using light scattering. The poly-dispersity of molecular weight for this methylcellulose was unknown due to the technical difficulty in determining it using GPC. The viscosity range was reported by the manufacturer to be 4.54 Pa.s at 20 °C for a 2 wt % aqueous solution. Although SM4000 is a commercial product, this material is considered to be highly pure. Concentration of aqueous cellulose derivative suspension of 0, 0.5, 1.0, 1.5 and 2.0 w/v% was tested to select the appropriate formulation for coating applications. Each concentration of MC was tested in triplicate.

3.4. Preparation of the MC solution

Aqueous solutions of methylcellulose were prepared on a w/v%, according to the hot/cold technique. The powder was dispersed into 1/3 of total water at 80˚C and gently mixing by magnetic stirred at room temperature until completely dissolve. Subsequently transferred the beaker with dispersed MC to a freezer for 12 minutes or until 10 ˚C and add the rest of water at 4 ˚C and stirred for 30 min allowing a correct MC hydration. Sorbitol with different concentration incorporated after MC had completely dissolved. Solutions were prepared the day before frying and kept at 4 ˚C. (Sanz et al., 2005)

3.5. Sample preparation

Samples of potato strips were punched by potato cutter with the dimension 8 x 8 x 60mm and subjected to a blanching treatment at 85 °C for 6 minutes, drained and dried in a convection oven at 150°C for 3 min to reduce the surface moisture (Pahade & Sakhale, 2012). Samples were dipped in the coating suspensions (varies concentration of MC) for 10s (García et al., 2002). Then, the samples were drained on a metal mesh to remove the excess surface solution for 3 min before frying.

3.6. Frying conditions

Coated and uncoated (control) samples were fried in a controlled temperature deep-fat fryer (Faber) filled with 1.5Lof commercial Buruh Cooking oil made from 100% high grade pure palm olein. Samples were positioned on a metal mesh basket and fried by immersed, in the hot oil at temperature 180±2 °C for 6 minutes (García et al., 2004; Tavera-Quiroz et al., 2012). Optimum time-temperature frying conditions were predetermined based on the sensory analysis; colour and overall appearance (García et al., 2002). Used oil was replaced by fresh oil after frying one batch. In each batch three potatoes were fried.

Raw potatoes

- Peeled and cut into (8x8x60mm) using potato cutter

↓

Rinse with distilled water and drain to dry

- To remove the loss starch and reduce the sugar before frying
- To prevent oil breakdown and darken the potato strips.

↓

Blanching

- With distilled water at 85 °C for 6 minutes

↓

Drying in convection oven at 150°C for 3 minutes

- To reduce the surface moisture

↓

Coating

- Dipped potato strip with MC solution at different concentration (0, 0.5, 1.0, 1.5, 2.0 w/v%) for 10 seconds
- Samples were drained on a metal mesh for 3 min before frying to remove the excess surface solution.

↓

Deep-fat frying

- 180±2 °C for 6 minutes

Figure 3. 2: Process flow of fried potato strip.

3.7 Analytical methods

3.7.1. Rheology measurements

The rheometer (Discovery Hybrid Rheometer) with the geometry of a parallel plate (40 mm) was used. The dynamic viscoelastic functions such as shear storage modulus G' and loss modulus G'' were measured as a function of temperature. A thin layer of low viscosity silicone oil was placed periphery surface of the solution held between the plates to prevent dehydration during the rheological measurements. G' and G'' as a function of angular frequency of a given temperature, the sample in the liquid state was first loaded to the bottom plate of the rheometer at room temperature and the temperature was raised to required temperature. Then, the sol-gel transition occurred at the desired temperature. (Wang & Li, 2005)

I. Temperature sweep test

All the dynamic viscoelastic measurements were carried out at an angular frequency, 1 rad/s and low shear strains (0.1%) to ensure the linearity of viscoelastic. G' and G'' were measured during a thermal cycle from 20 to 90°C and subsequently cooling from 90 to 20°C at the heating and cooling rate of 1°C/min (Wang & Li, 2005).

3.7.2. Microstructure observation

The light microscope was used for the observation of microstructural changes of fried potato strips. First, the oil uptake at the surface of potato strip after fry was removed from oil absorbing cooking paper. Then the samples were fixed to the sample support. Finally, potato strip samples were observed, and the images were captured under the polarization field coverage by Leicca ICC 50 HD light microscope(Chen et al., 2018).

3.7.3. Water content

The coated and uncoated fried potatoes were transferred to an oven at 110 °C until a constant weight was reached(García et al., 2004). Water content (WC) was determined by measuring the weight loss of fried products during the drying process. The average result for triplicate sample was obtained in wet basis (wt%). Relative water retention % (WR) in the coated product relative to the uncoated one was calculated as follows:

$$WR = \left(\frac{WC_{coated}}{WC_{uncoated}} - 1\right) X\ 100 \qquad (1)$$

where: WCcoated and WCuncoated are the water contents of the coated and uncoated samples respectively.

3.7.4. Lipid content

Lipid content (LC) of fried products was determined on dried samples using a semi-continuous Soxhlet extractions. The Soxhlet extraction with n-hexane (n-hexane extract) was carried out (García et al., 2004; Kim et al., 2011). The oil content of potato strips indicates the total amount of oil uptake during frying process.

Dried potato strips for moisture analysis was utilized for oil uptake analysis during frying. Dried samples are blended into smaller pieces to ensure oil was fully extracted from the samples. A volume of 90ml of n-hexane solvent was added to the extraction cup. The system is set to 150 °C (hot extraction) for total fat extraction analysis. There will be four step cycle includes to run a complete extraction which is boiling, rinsing, solvent recovery and pre-drying process. The extraction time was one hour fifteen minutes.

The samples were analysed in triplicate and the oil content was expressed as a wet basis. Relative variation of an oil uptake % (OU) in the coated product relative to the uncoated one was calculated as follows:

$$LC = \left(\frac{LC_{coated}}{LC_{uncoated}} - 1\right) X\ 100 \qquad (2)$$

where: LCcoated and LCuncoated are the lipid contents of the coated and uncoated samples respectively.

CHAPTER 4

RESULTS AND DISSCUSION

4.0. Introduction

This chapter discusses on the findings of this study. In section 4.2 of this chapter discusses on the flow properties of the Methylcellulose solution in water. Section 4.3 discusses about the viscoelasticity behaviour of Methylcellulose in water. On the hands, the effect of different concentration of Methylcellulose coating on moisture content and oil uptake is discussed in section 4.4 and section 4.5. The discussion of the relationship between thermo reversible properties with the oil uptake and moisture content in deep-fat frying showed in section 4.6. While, the effect of concentration of Methylcellulose on the gelation time and the relation between gelation time and oil uptake was discussed in section 4.7. Last but not least, Section 4.8 showed the light microscope photography analysis on the surface morphology of fried potato strips.

4.2. Flow properties of the Methylcellulose solution

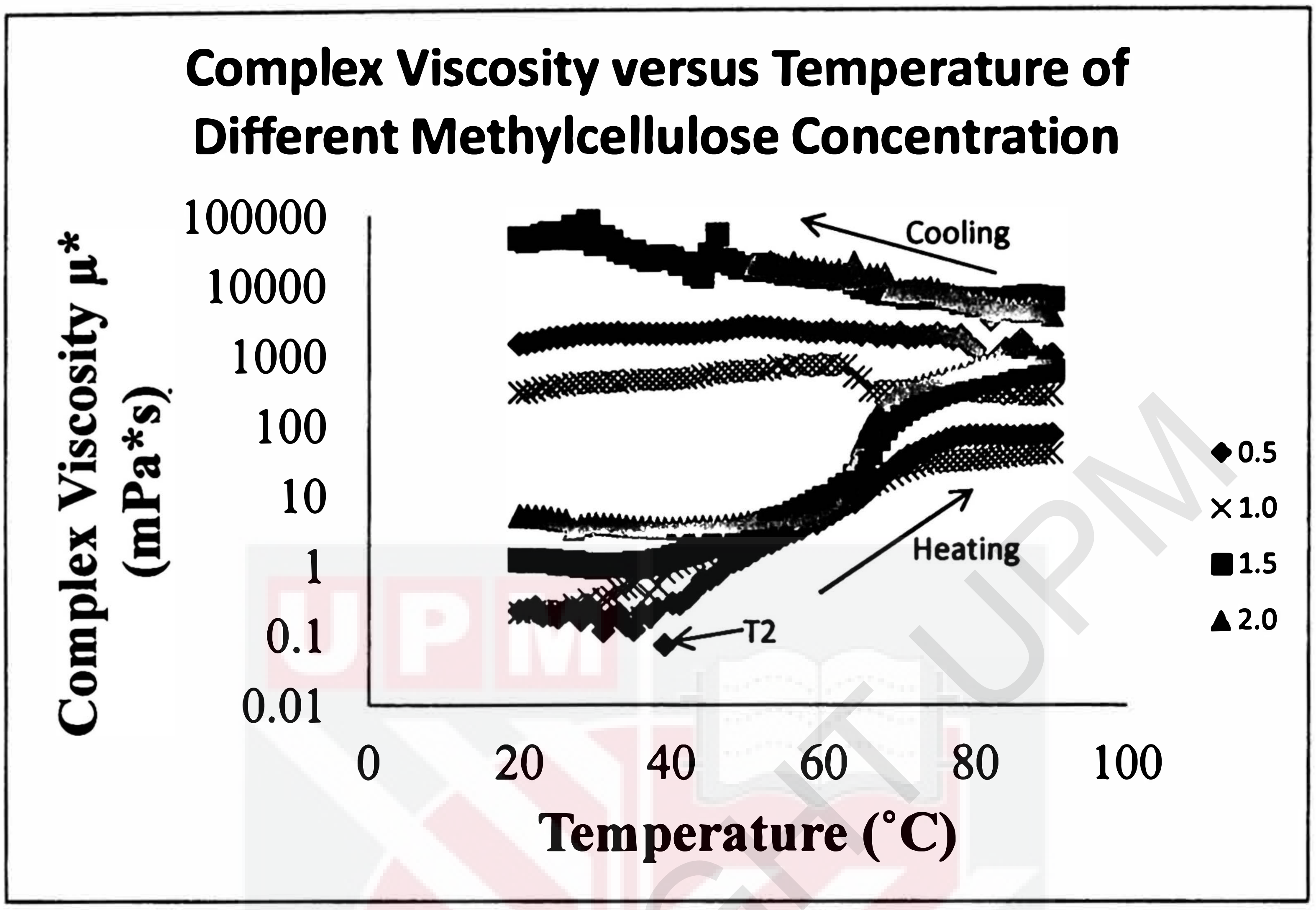


Figure 4. 1: Complex viscosity as a function of temperature (sweep rate 1˚C/min) for A4M solutions of different concentration.

The result in aqueous solutions of the Methylcellulose is illustrated as a function of temperature and concentration in figure 4.1. The complex viscosity was obtained from Bodvik et. al (2010) research and the data were obtained at the heating and cooling rate of 1˚C/min. Arrows along the curve indicate the direction of temperature sweep and the temperature at which viscosity reaches its minimum value is conventionally called T2. From the results, it can be observed that viscosity increases with polymer concentration, 0.5-2.0wt%. The results show the same features with other researches(Bodvik et al., 2010).

For 0.5wt% sample, on heating, temperature up to 39°C (T2) leads to a reduction in viscosity. But after the T2, it shows an increasing of viscosity with increasing the temperature. The viscosity of the methylcellulose solution may affect the coating behaviour when apply in fried potato.

On the other hands, a graph of T2 versus concentration of A4M solutions at sweep rate 1°C/min can be drawn as shown in figure 4.2. From the graph, T2 values decrease linearly with concentrations and the trend line can be described by the equation:

T2 = 43.5-8C

This relation is valid only for the A4M solutions with heating rate 1°C/min used, and the accuracy should not be overestimated. From the equation, the temperature required to obtain the viscosity with minimum concentration was 43.5°C.

Therefore, a minimum temperature can be predicted for different concentration of Methylcellulose solution to achieve the minimum viscosity when applying as a coating in fried product.

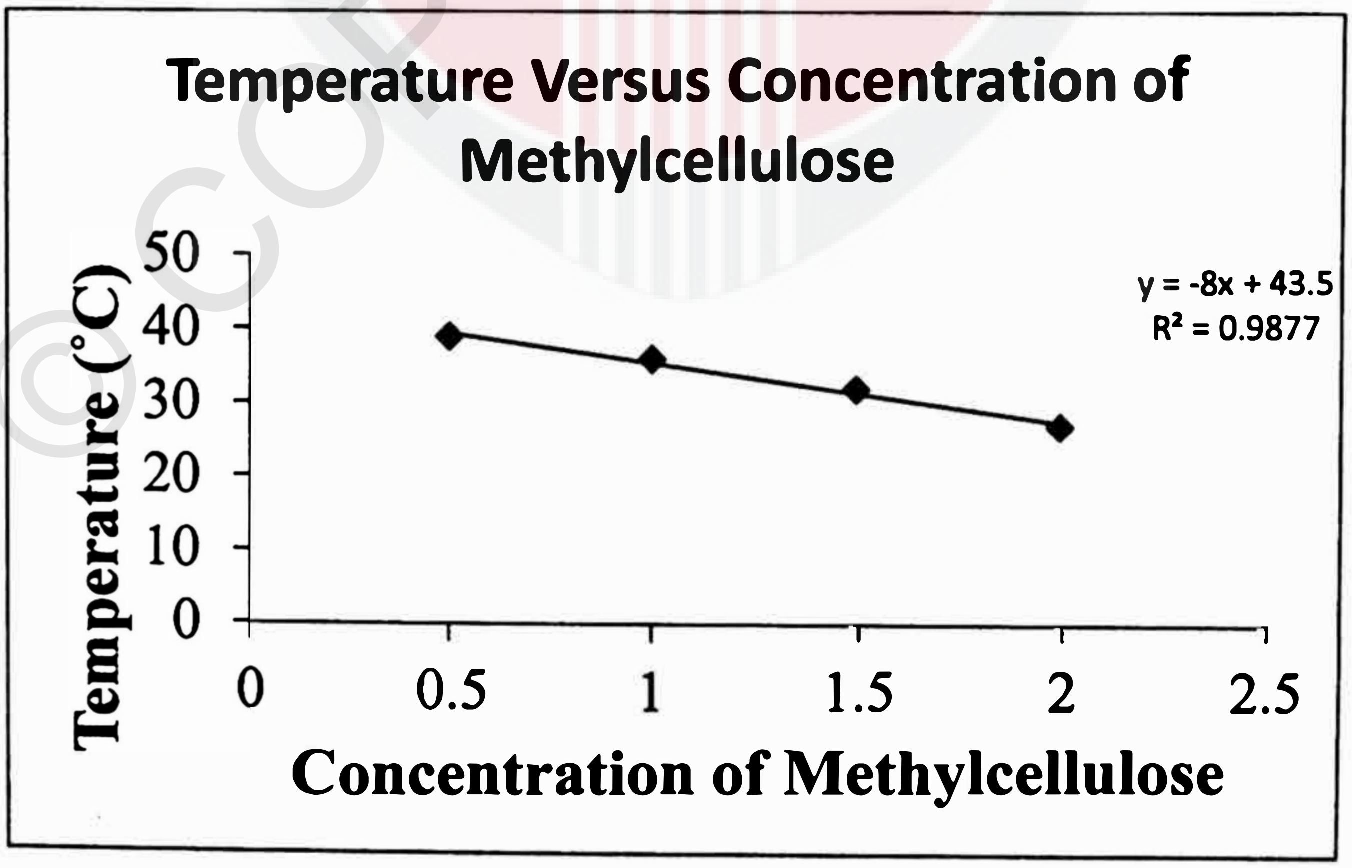


Figure 4. 2: T2 versus concentration for A4M solutions at the sweep rate 1°C/min

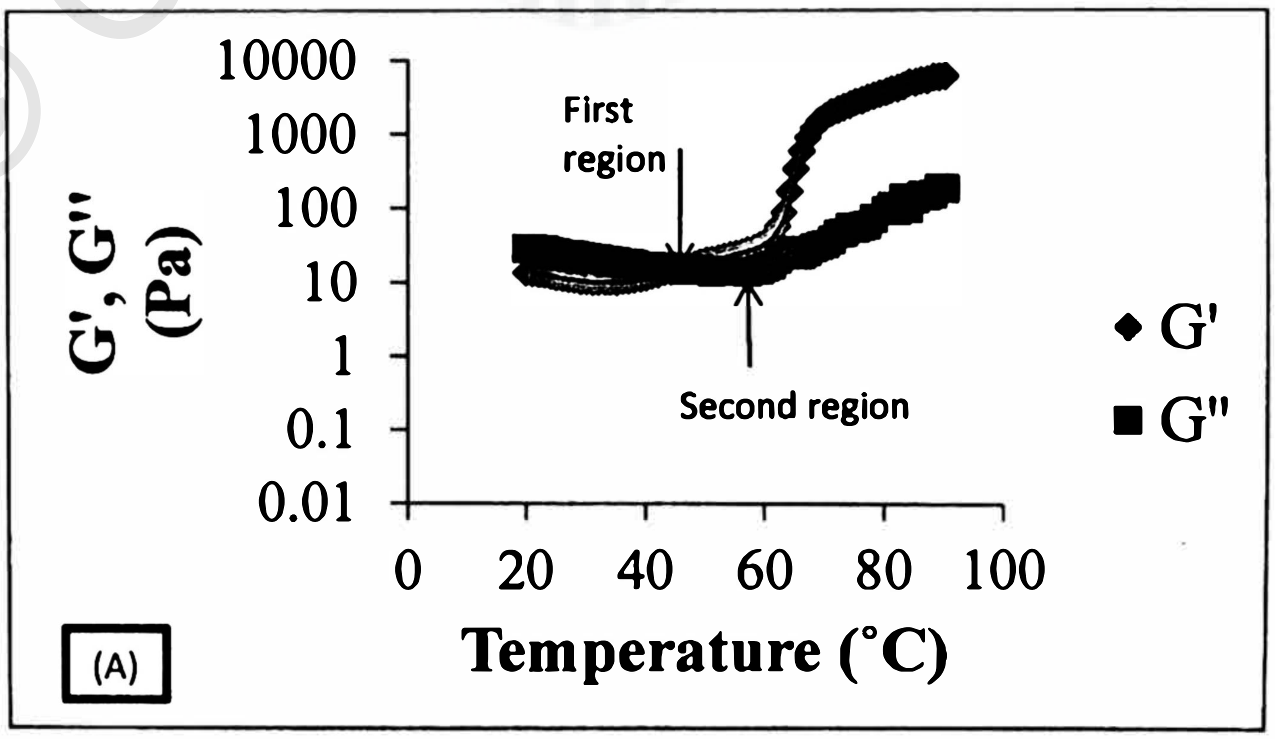
4.3. Determination of viscoelastic behaviour of Methylcellulose solution in water.

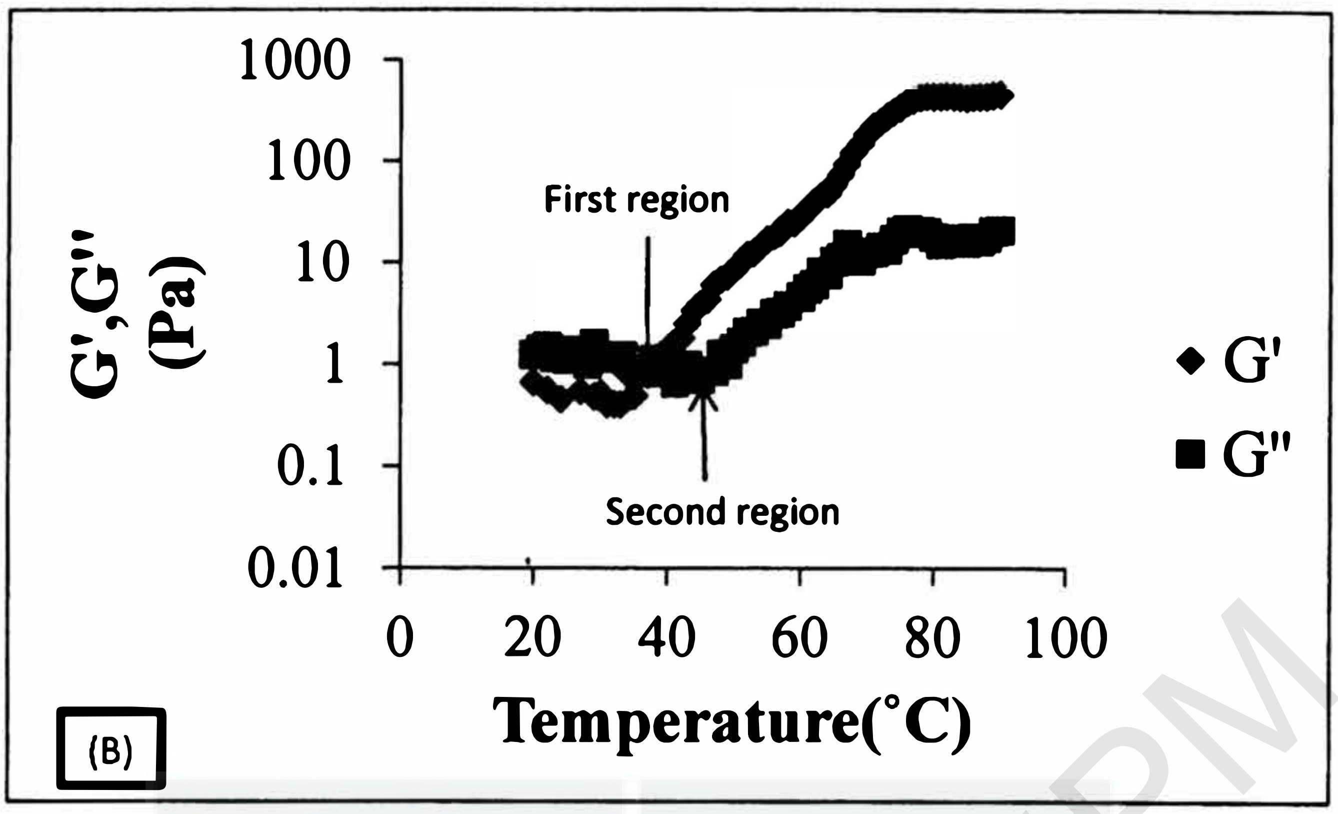
4.3.1. Gelation

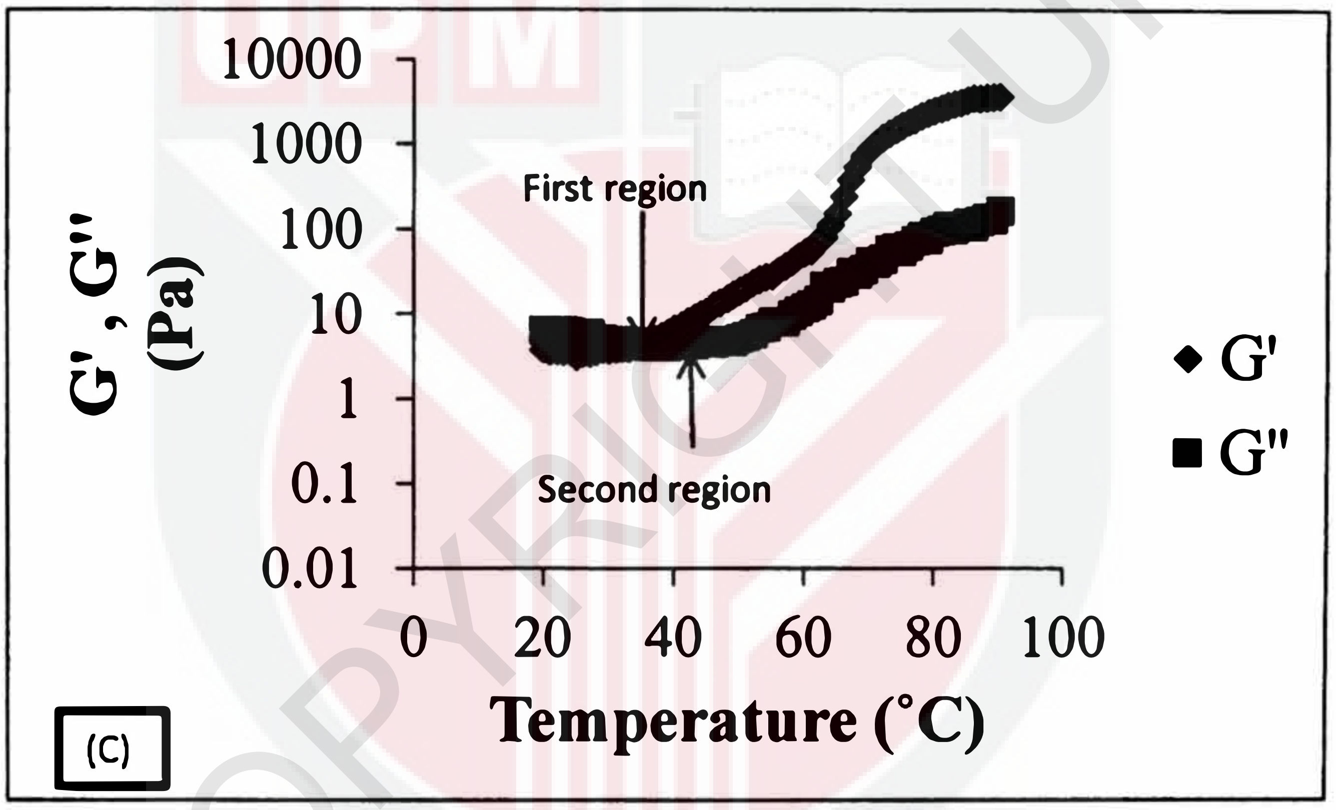
As shown in figure 4.3, the heating process from 20°C to 90°C, there are two distinct regions. For 0.5wt% Methylcellulose sample, the first region is at 46°C where G'' crosses over G'. This region is showing the common viscoelastic behaviour of a liquid. For the second region, the G' is gradually increased with temperature while G'' decrease slightly until 55 °C. A consideration that a weak but elastic structure of Methylcellulose is formed in water since G' is higher than G''. This result is similar to the finding by Wang, Li, Liu, Xu, & Liu (2006)

Besides, from the graph obtained, we can conclude that G' and G'' are not only depend on the temperature but also the concentration of Methylcellulose. The region for the common viscoelastic behaviour of Methylcellulose decreases with increasing the concentration of Methylcellulose solution. So, the gelation temperature for various concentrations can be determined which is important for gelation mechanism when applying in high temperature frying condition.

Figure 4. 3: Storage modulus, G' and loss modulus, G'' as a function of temperature in a heating process for Methylcellulose solutions. (a)0.5wt% (b) 1.0wt% (c) 1.5wt% (d)2.0wt%.




1000
100
10
1
0.1
0.01
G',G''
(Pa)
First region
Second region
0
20
40
60
80
100
Temperature(˚C)
G'
G''
(B)


10000
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G', G''
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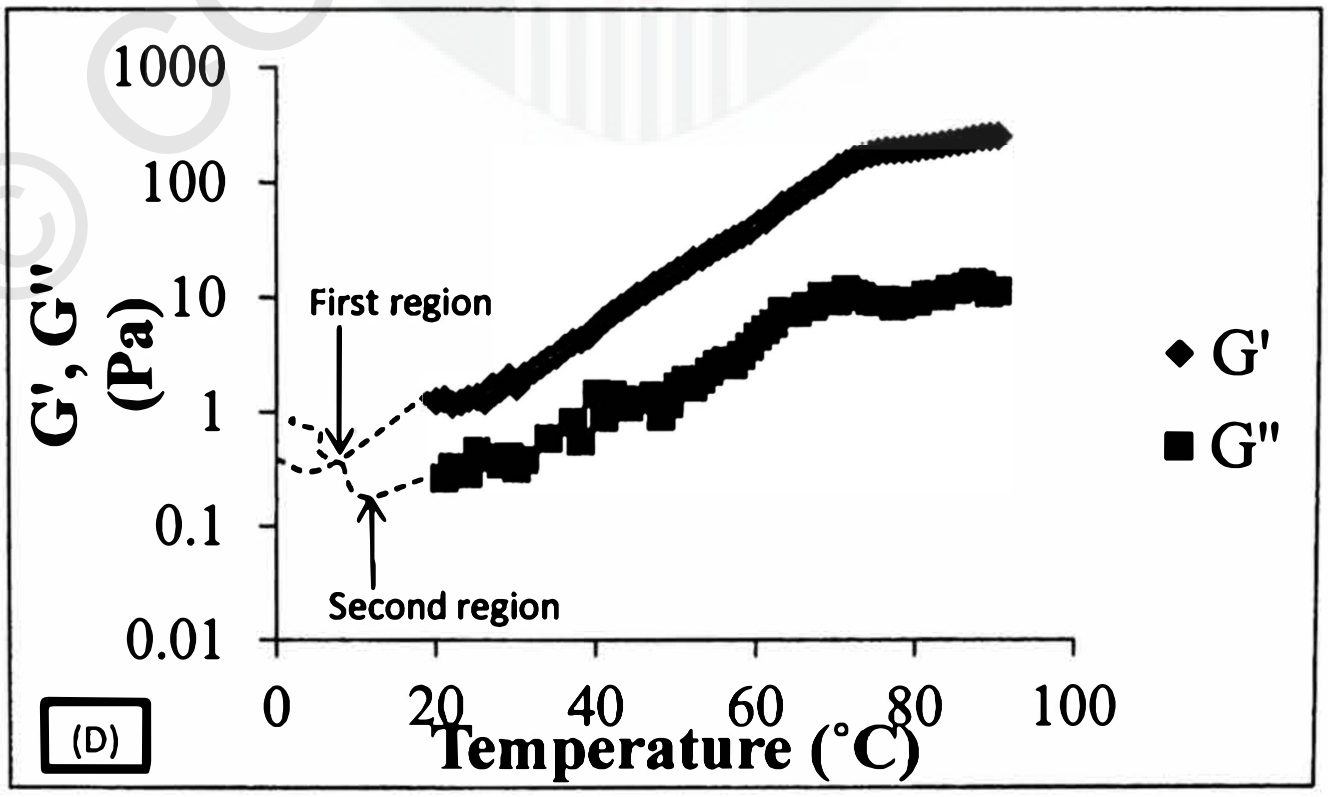
Temperature (˚C)
G'
G''
(C)


1000
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1
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G', G''
(Pa)
First region
Second region
0
20
40
60
80
100
Temperature (˚C)
G'
G''
(D)

Table 4. 1: Effect of Methylcellulose concentration on the gelation time based on the temperature different obtained from Figure 4.3

MC CONCENTRATION	TEMPERATURE (˚C)		TEMPERATURE DIFFERENCE (˚C)	GELATION TIME (s)
	1st Region	2nd region		
0.5% MC	46.0	55.0	9.0	9.0
1.0% MC	39.0	42.0	3.0	3.0
1.5%MC	36.0	41.0	5.0	5.0
2.0%MC	9.0	16.0	7.0	7.0

According to Wang, Li, Liu, Xu, & Liu (2006), the gelation process undergoes in between the first and second region where the gelation time can be estimated from the results. In table 4.1, the gelation time for 1wt% of Methylcellulose to form a gel like solution is only 3 minutes, while 0.5wt% of Methylcellulose take longer time to form a gel structure as the water molecules available in the solution are high. Therefore, a longer time must be taken for water molecules to react with the Methylcellulose structure to become gel like solution when heating.

For the 1.5wt% and 2.0wt% of methylcellulose, the time required for gelation occurred takes longer time compared to 1wt% concentration. However, from the temperature of gelation start, the concentration of Methylcellulose is inversely proportional to the starting point of gelation temperature occurred. The increasing in concentration of methylcellulose, the lower the temperature required for the gelation process (Collini, Mohr, Luckham, Shan, & Russell, 2018).

4.3.2. Mechanical spectra

Figure 4.4 shows the dynamic storage modulus G' as a function of angular frequency, ω for various concentrations of Methylcellulose at 90°C. According to Li (2002), G' exhibits a weak dependence on ω, and the ω dependence decreases with increasing polymer concentration. From the results, 2.0wt% of Methylcellulose solution showed a nice plateau compared to 0.5 and 1.0wt% of Methylcellulose concentration as G' is almost independent of ω in high concentration. From the statements, we can conclude that the time for high concentration of Methylcellulose to gelation does not depend on the angular frequency but more on the temperature sweep.

Therefore, a hypothesis that the similar gel network structure would be formed when fixed the temperature for different concentration and angular frequency can be predicted. At low concentration, there is a weak gel network structure compare to 2.0wt% Methylcellulose concentration.

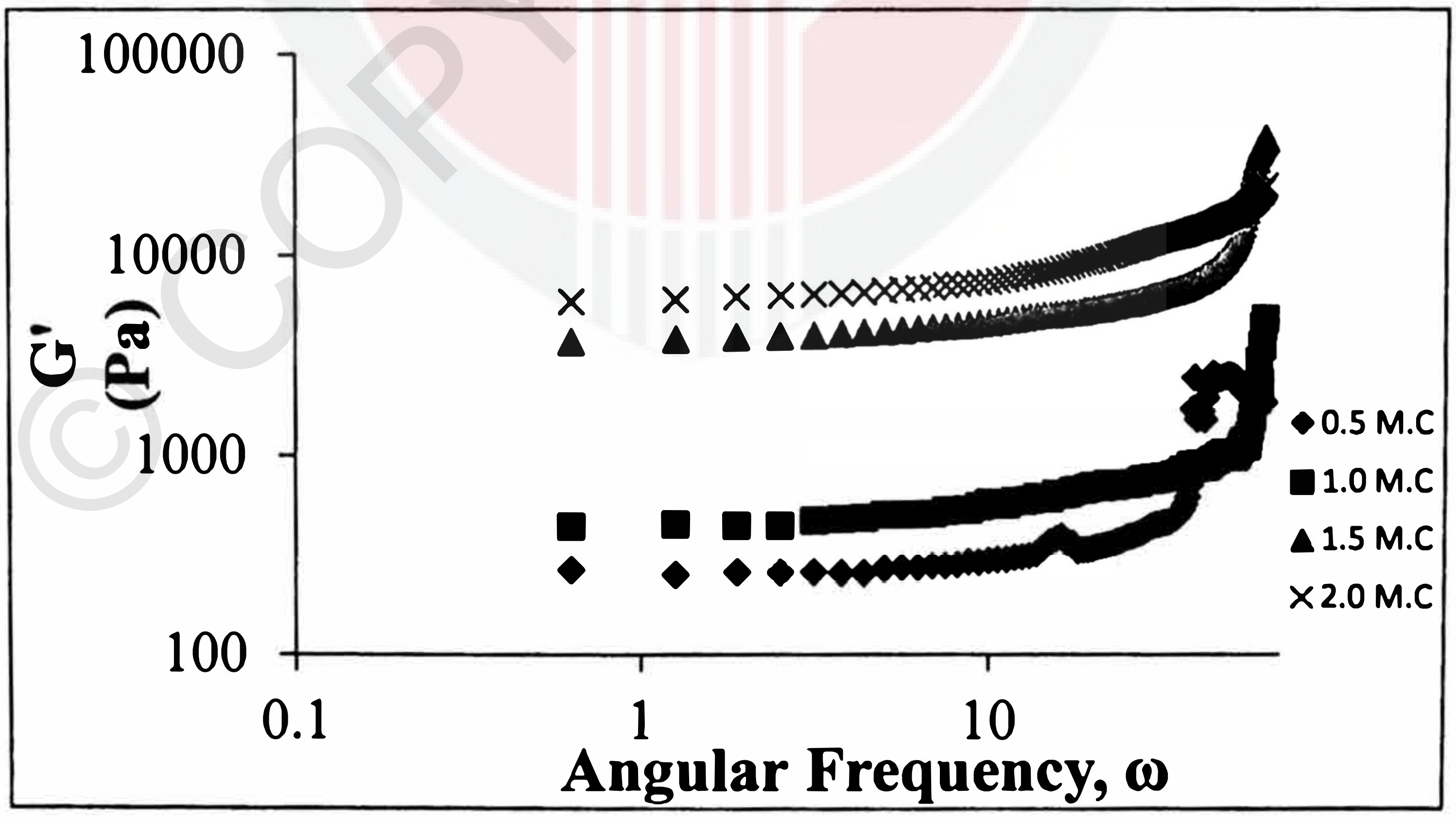

Figure 4. 4: Storage modulus G' as a function of angular concentrations, ω for various concentration of A4M at 90°C.

4.4. Effect of different concentration of Methylcellulose coating on moisture loss and water retention.

Table 4. 2: Effect of Methylcellulose coating with various concentrations of initial moisture content (MC), moisture loss during frying (%WL) and relative variation of water retention (%WR).

MC CONCENTRATION	MC	%WL	%WR
Control	3.0229±0.1671	81.2132±0.9711	-
0.5% MC	3.1841±0.1678	79.7495±0.9187	24.5735±0.0441
1.0% MC	3.6903±0.3565	75.6377±0.7313	57.8991±0.0727
1.5%MC	4.0398±0.2700	78.5766±0.6130	46.2102±0.0315
2.0%MC	3.5902±0.3465	80.0568±0.7702	26.2208±0.0954

The following visual observations were made during simultaneous frying of coated and uncoated potato strip. Initially, coated samples produced more bubbles compared to uncoated samples. As frying progressed, a reversal in the trend was observed with uncoated sample forming larger bubbles compared to coated samples. This showed that uncoated potato samples were losing more moisture to frying medium than coated samples during frying process. Table 4.1 tabulated the effect of Methylcellulose coating with various concentrations on initial moisture content, moisture loss during frying and relative variation of water retention for the five samples of fried potato in the frying conditions 6 min at 180°C.

Figure 4.5 and 4.6 show 1wt% of Methylcellulose solution coating on potato strips has the lowest percentage of moisture loss during frying and highest percentage of water retention in potato. There are slightly significant different in the MC coated and uncoated samples to moisture loss in the end product by 1-6% as compared with the control product. According to Garcia et al. (2002), MC coating treatment significantly ($P<0.05$) reduced oil uptake and increased water retention of fried potato compared to uncoated. Similar results are obtained by applying different cellulose derivative coating in various types of products (Angor, 2016; García, Ferrero, Bértola, Martino, & Zaritzky, 2002; Garmakhany, Mirzaei, Nejad, & Maghsudlo, 2008; Mallikarjunan, Chinnan, Balasubramaniam, & Phillips, 1997; Tavera-Quiroz, Urriza, Pinotti, & Bertola, 2012)

On the other hands, it was notified that the percentage of water loss and water retention in end products showed fluctuated. This can be explained by the result of flow properties of methylcellulose solutions in Figure 4.1 where the viscosity was increased by increasing the concentration of MC solution. However, the methylcellulose concentration will affect the viscosity and the pickup effectiveness of the coating. According the Fiszman & Salvador (2003) research, the thickness of layer coating affects the effectiveness of hydrocolloids to function as a water barrier during frying process. A too thin layer of coating may cause difficulty in handling and resulting in poor barrier effect before and during frying. While, a layer that is too thick may lead to an incompletely cooked final product.

Moreover, Figure 4.5 shows the relative variation of water retention (%WR) in the coated product relative to control product which is uncoated end product. The water retention ability is related to the ability of hydrocolloid to form a fine net structure of the gel-forming compounds that may alter the water holding capacity and consequently affect the oil uptake during and after frying process (Rimac-Brnčić, Lelas, Rade, & Šimundić, 2004). The effect of MC concentration and temperature on the water retention capacity was discussed in Section 4.3. Based on the Sanz, Salvador, & Fiszman (2004) research, MC concentration increased showing the powerful ability of MC chain to retain water. However, the water retention capacity may be affected by the temperature and flow properties of methylcellulose solution.

From the graph obtained, it shows the water content after frying processes in all coated products are relatively higher than uncoated product. The positive value of percentage water retention in coated fried potatoes is relative to uncoated fried potatoes mean the Methylcellulose of different concentration coating are able to form a protective layer when product introduced into hot oil.

Methylcellulose is water soluble ether with high water holding capacity and good film forming property which may develop high consistency and water retention properties. Therefore, MC was used for this study compared to CMC and HPMC in fried potatoes(García et al., 2002; Mallikarjunan et al., 1997).

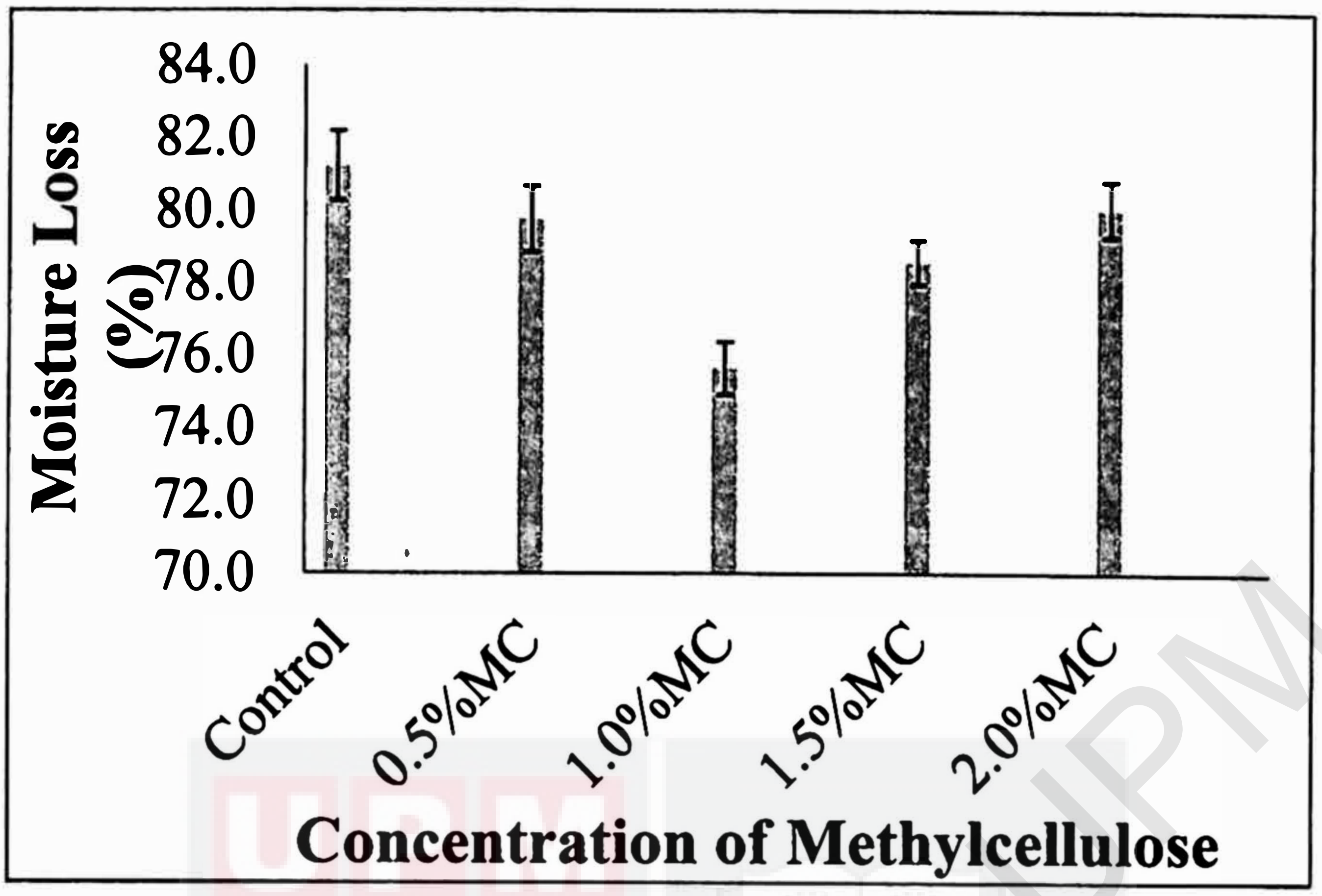

Figure 4. 5: Percentage of moisture loss with different concentration of Methylcellulose as a coating layer for deep-fat fried potatoes.

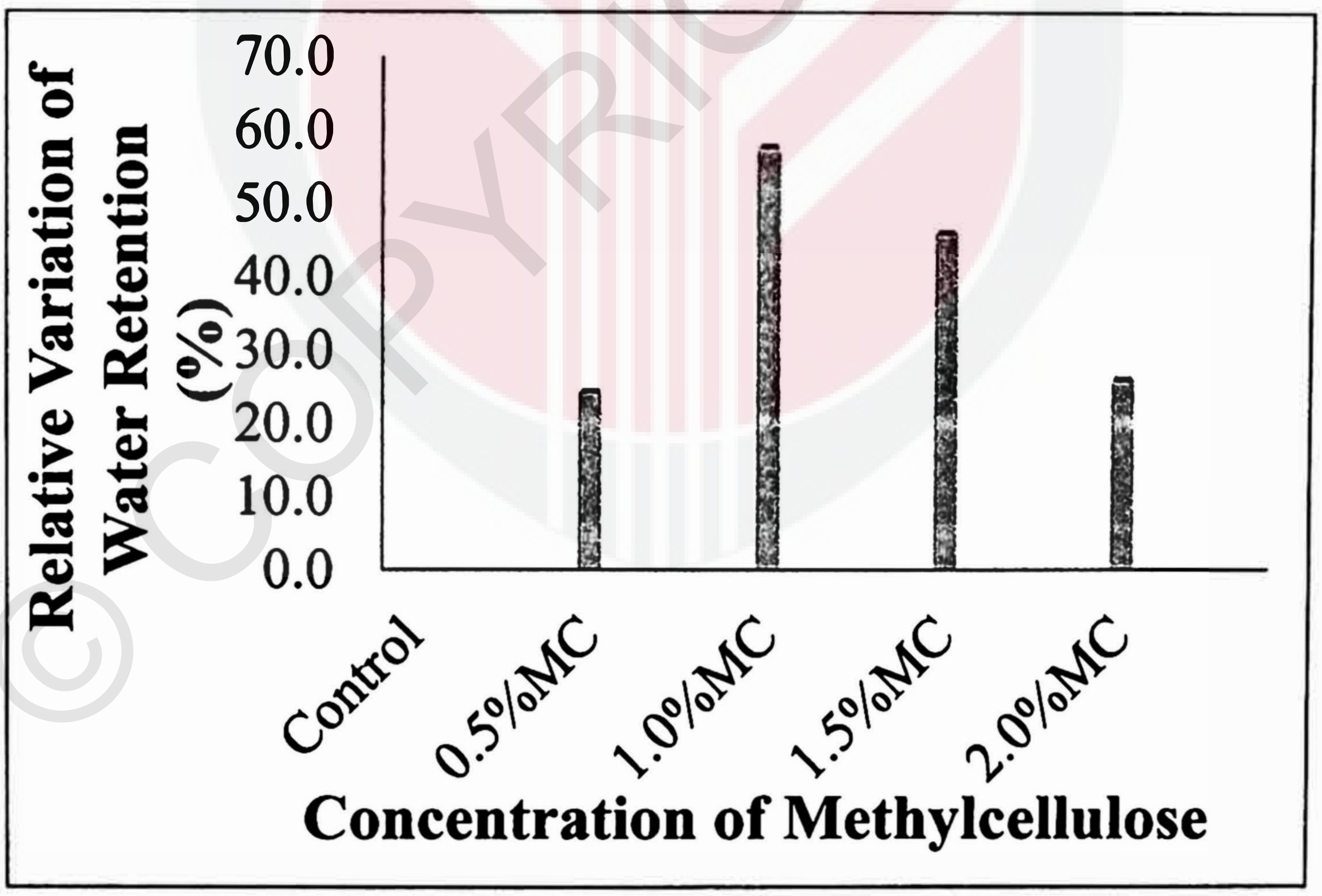

Figure 4. 6: Percentage of relative variation of water retention with different concentration of Methylcellulose as a coating layer of deep-fat fried potatoes.

4.5. Effect of different concentration of Methylcellulose coating on oil uptake.

Table 4. 3: Effect of Methylcellulose coating with various concentrations on the percentage of oil uptake (%OU) and the percentage of relative variation of oil reduction (%OR)

MC CONCENTRATION	%OU	%OR
Control	46.2400±0.05237	
0.5% MC	29.1033±0.0922	35.0369±2.7215
1.0% MC	25.2100±0.0593	44.3761±1.8422
1.5%MC	28.7700±0.0356	39.2837±1.2008
2.0%MC	28.9532±0.0412	38.6914±2.1715

Table 4.2 shows the percentage of oil uptake obtained with various concentrations of MC as a hydrocolloid coating in deep-fat frying. The result indicates that the effectiveness of using MC as an oil and moisture barrier in comparison with the control can be clearly seen.

In addition, the oil reduction in comparison with the control with considered as 100% of oil absorption of the 0.5, 1.0, 1.5 and 2.0wt% MC solutions were 35.0, 44.4, 39.3 and 38.7% respectively was shown in Figure 4.8. Of note is the more evident effect of the barrier properties of MC during and after frying process of potato strips. This might relate to the heat and mass transfer mechanism during the frying process of the potato strip. The percentage of retention variation of oil reduction had been always negative in value as the lipid content of coated sample was lower than the uncoated sample.

Hubbard & Farkas (2000) state that oil temperature effects on heat flux and convective heat transfer coefficient during immersion frying. Increased oil temperatures provided increased heat sinks which mean more energy available for consumption in the dehydration process that occurs during frying. Furthermore, the difference in oil uptake is related to the mass transfer mechanism that is associated with the void structure or pore distribution during frying process(Soorgi et al., 2012). Formation of a uniform coating on the surface of the sample is needed to limit mass transfer during frying (Huse et al., 1998)

By the way, frying conditions like frying time and temperature have affected the formation of larger pores which leads to water evaporation and oil absorption. Van Koerten et al. (2015), concluded that the frying temperature is in the range of 180-195˚C to improve the crispy properties of the fries. Moreover, Gupta et al. (2000) also states that French fries prepared from blanched potato strips without pre-drying at 180˚C received highest acceptability score.

On the other hands, MC has reversible thermo-gelation properties where there is formation of gel upon heating above 43.5˚C and should be melts once sample reaches ambient temperature(García et al., 2002). Thermo-gelling could lead to a stronger coating that limiting oil absorption after frying by reduction of pore size and quantity. According to Mellema (2003), no oil-uptake occurs during frying, but absorption of oil occurs on the surface of the fried product when samples removed from the frying medium. Generally, the oil uptake phenomena explained by two possible mechanisms which are water displacement and adsorption during cooling phase (Mellema, 2003; Saguy & Dana, 2003).

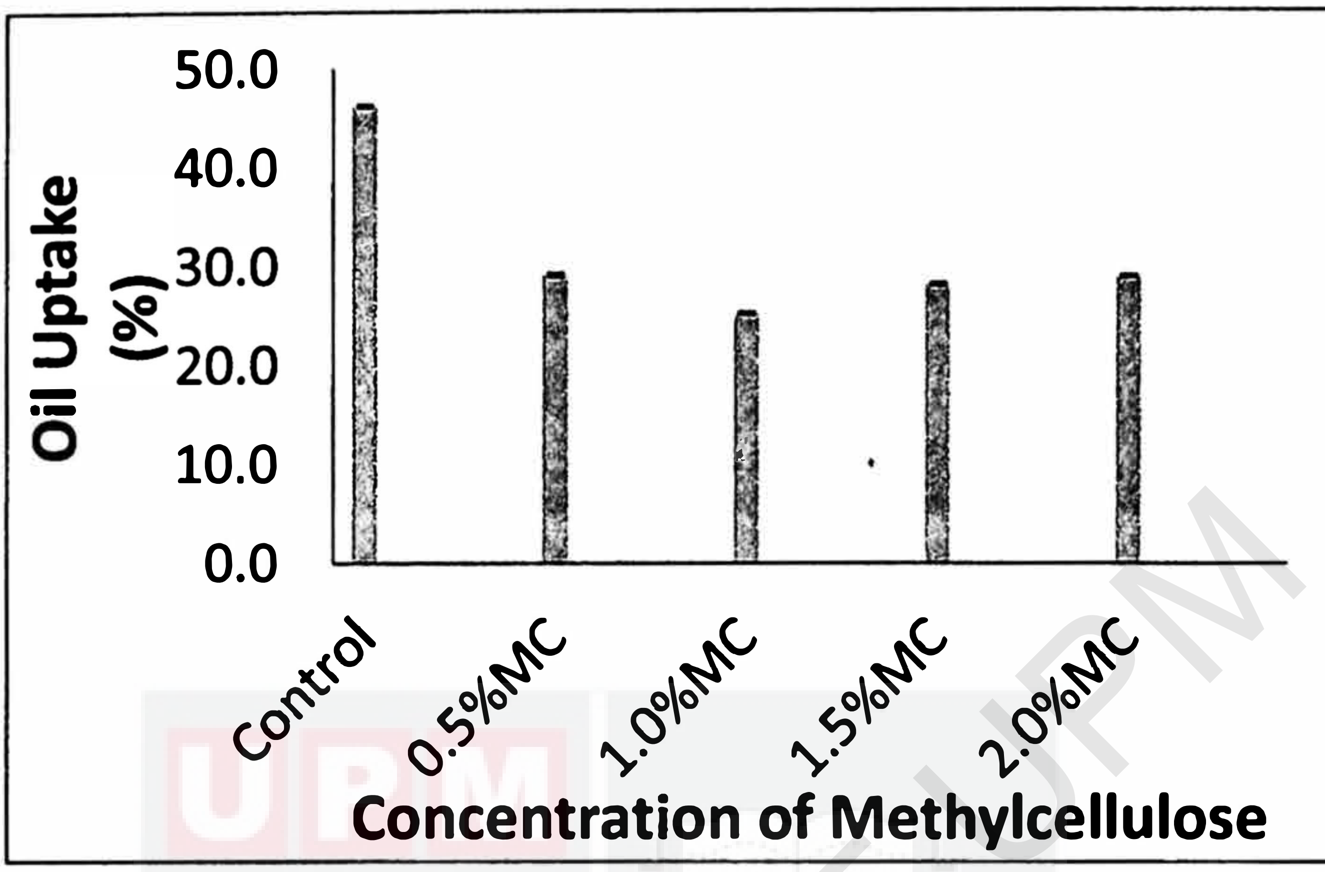

Figure 4. 7: Percentage of oil uptake with different concentration of Methylcellulose as a coating layer of deep-fat fried potatoes.

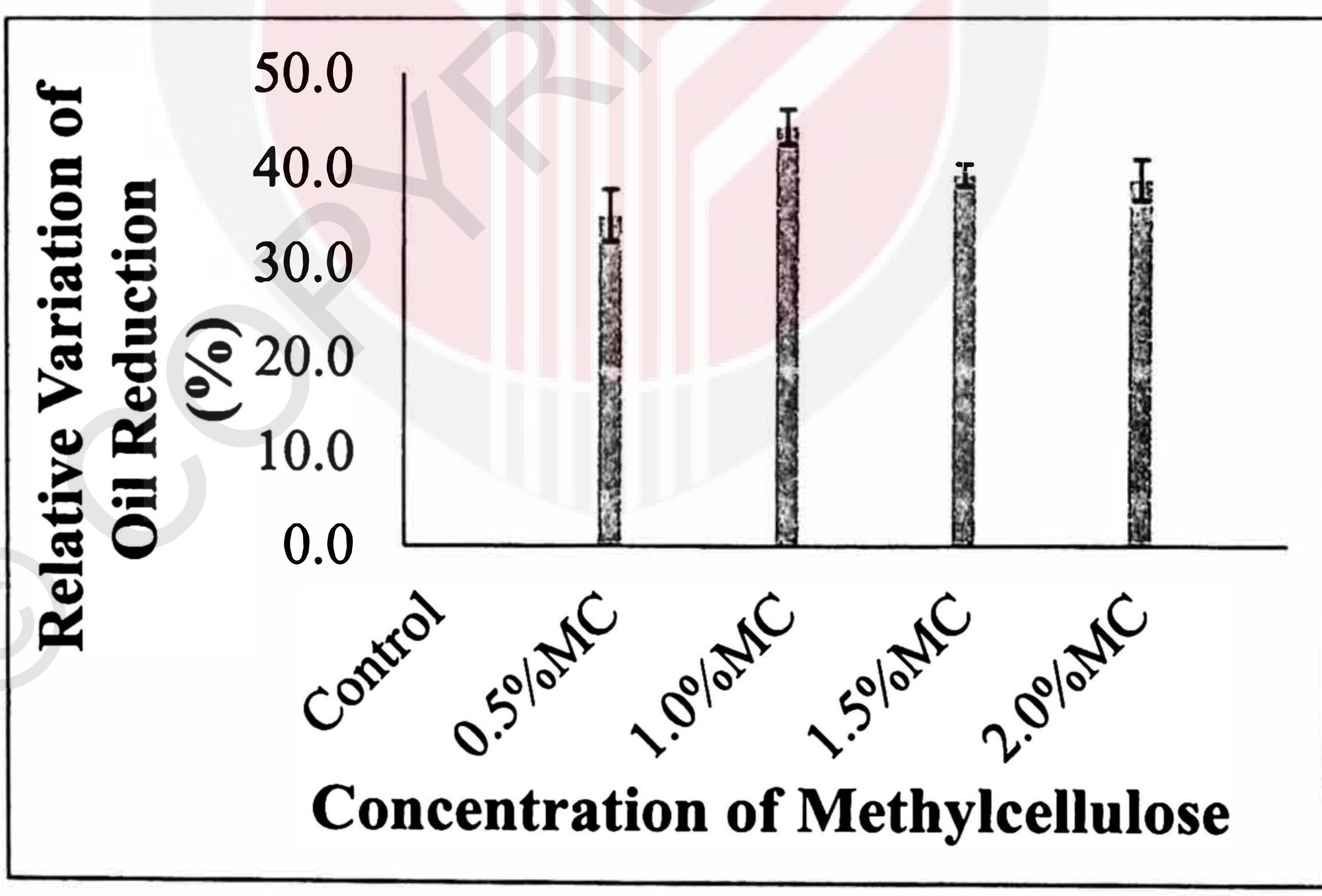

Figure 4. 8: Percentage of relative variation of oil reduction with different concentration of Methylcellulose as a coating layer of deep-fat fried potatoes.

4.6. Effect of thermal reversible on the oil uptake and water loss.

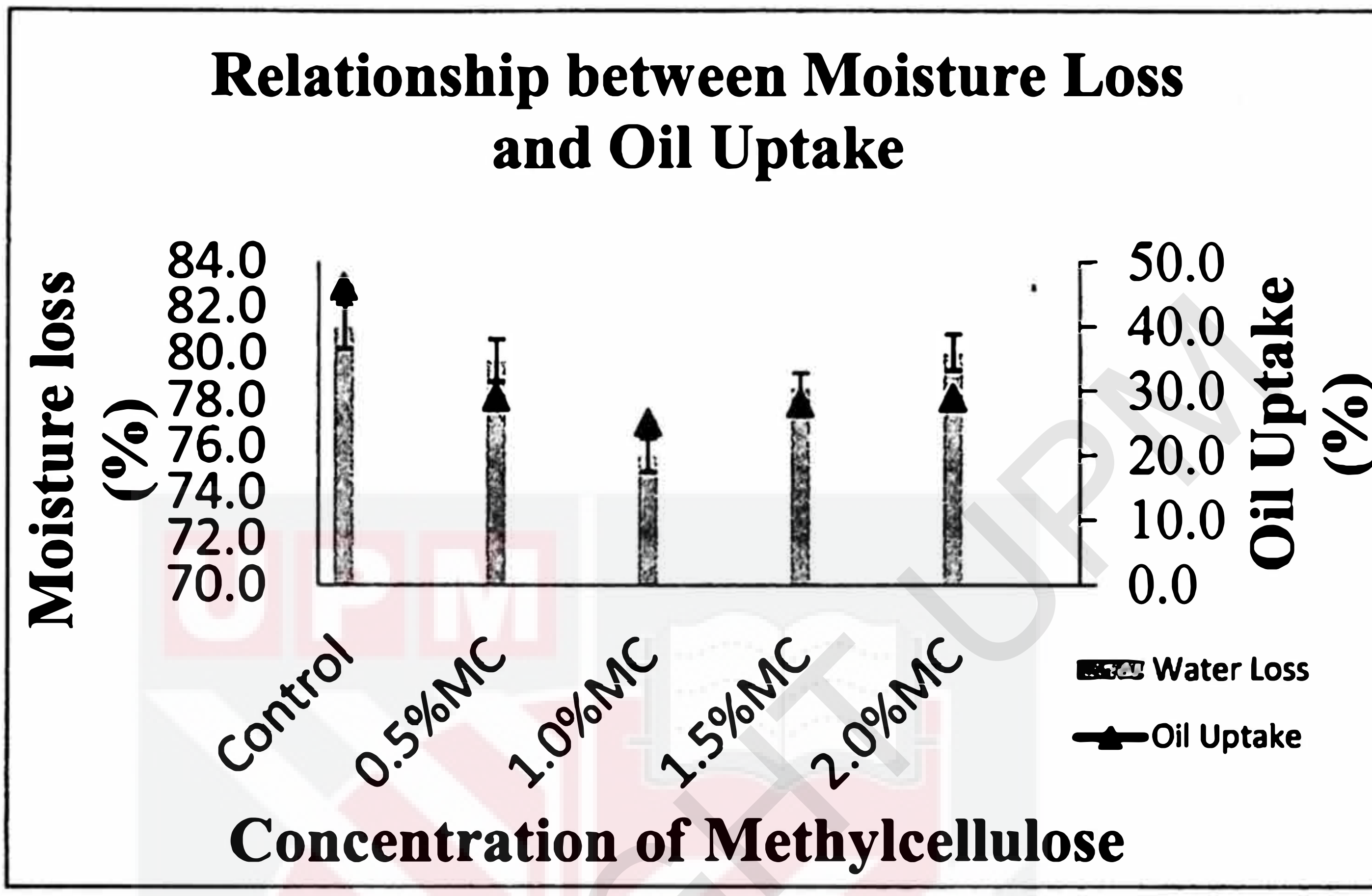

Figure 4. 9: Relationship oil adsorption and water loss affect the coating formulation.

Increasing MC concentration produced a significant reduction in oil absorption and increases in water retention. Figure 4.9 shows the oil uptake is proportional to the moisture loss for deep-fat frying. During frying, the void created because of water evaporation allows penetration of oil or fat after removing from the frying medium(Mellema, 2003).

Through the light microscope image in Figure 4.11may explain the differences found in those samples that related to a trend toward the water loss and oil uptake in deep frying. From the results, microstructure of potato strip with 1.0wt% of methylcellulose coating showed the smaller and lesser voids than other samples. Therefore, we can relate that the microstructure obtained with the oil uptake during deep frying. This result had been shown in Mellema (2003) findings.

In this section, we can conclude that 1.0wt% of Methylcellulose solution as coating treatment in potato fries is the most effective to reduce oil uptake and moisture loss. These differences in the adequate MC solution of coating formulations could be attributed to differences in adhesion between substrate and coating suspension, thermo gelling behaviour, surface characteristics of the sample and the last is the frying conditions.

4.7. Effect of gelation time of Methylcellulose on different concentration.

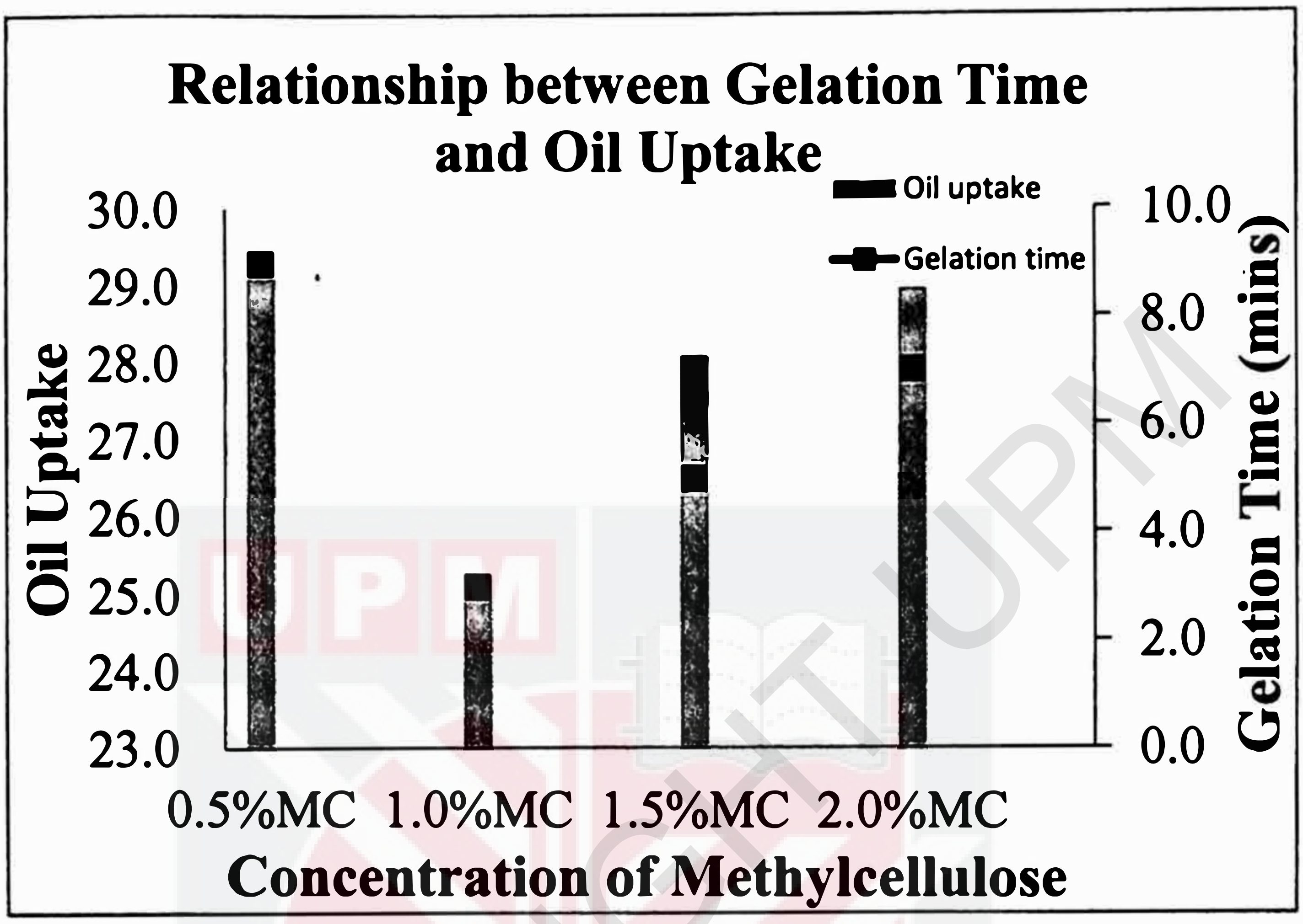

Figure 4. 10: Relationship oil adsorption and gelation time affect by the coating formulation.

In this section, it can be observed from Figure 4.10 where the effect of varying the Methylcellulose concentration on the gelation time of Methylcellulose solution and the relationship between the gelation time and the oil uptake of frying potato samples. The Methylcellulose concentration of the solution for the sample used ranged between 0.5% to 2.0%wt.

From table 4.1, at 0.5%wt of Methylcellulose, gelation taking the longest time, typically 9-10 minutes, while the shorter gelation time occurred at 1.0%wt of Methylcellulose. However, increased the Methylcellulose concentration to 2.0%wt increasing the gelation time where the gel formation becomes hard to induce. As methylcellulose is a hydrocolloid having thermal reversible properties, so the shorter the gelation time is required to achieve a strong gel for coating on the samples(Collini, Mohr, Luckham, Shan, & Russell, 2018).

Based on the Figure 4.10, there is a relationship between the oil uptake of potato samples after fried and the gelation time of varying concentration of Methylcellulose. The trend line of the results obtained shows the shorter gelation taking place, the lower the oil uptake of the coated fried potato sample. In short, it can be concluded that 1%wt concentration of methylcellulose is the best formulation for fried potato strip formulation in this study.

4.8.Morphological observation of fried potato strip samples

4.8.1. Light Microscopy analysis

Microstructure observation was done using Leicca ICC 50 HD light microscope with (5x0.12) in this section to observe the effectiveness of Methylcellulose coating on the surface morphology of potato strips after frying process. And also, the results obtained might explained for the oil uptake and the moisture loss in the previous section.

Figure 4.11 shows the surface morphology of deep frying potato strip uncoated and coated potato strips with various concentrations of Methylcellulose. Figure 4.11A show that uncoated fried potato strip with a combination of small and large void obtained on the surface of fried potato. Based on Mellema (2003) results, the amounts and size of the voids obtained might affect the oil uptake during frying process.

In Figure 4.11B, 4.11D and 4.11E, the voids are lesser compared to Figure 4.11A. This showed that applying Methylcellulose as a barrier of oil uptake during frying process was working and this result obtained was same as the experiment done by García et al. (2002). While, the best surface morphology with smaller and lesser pores or voids showed in Figure 4.11C which the potato strip was coated with 1.0wt% of Methylcellulose solution.

As a result, the surface morphology obtained was a strong explanation that related to the moisture loss and the oil uptake in the fried potato strips. This explanation was also done by Mellema (2003) and Saguy & Dana (2003).

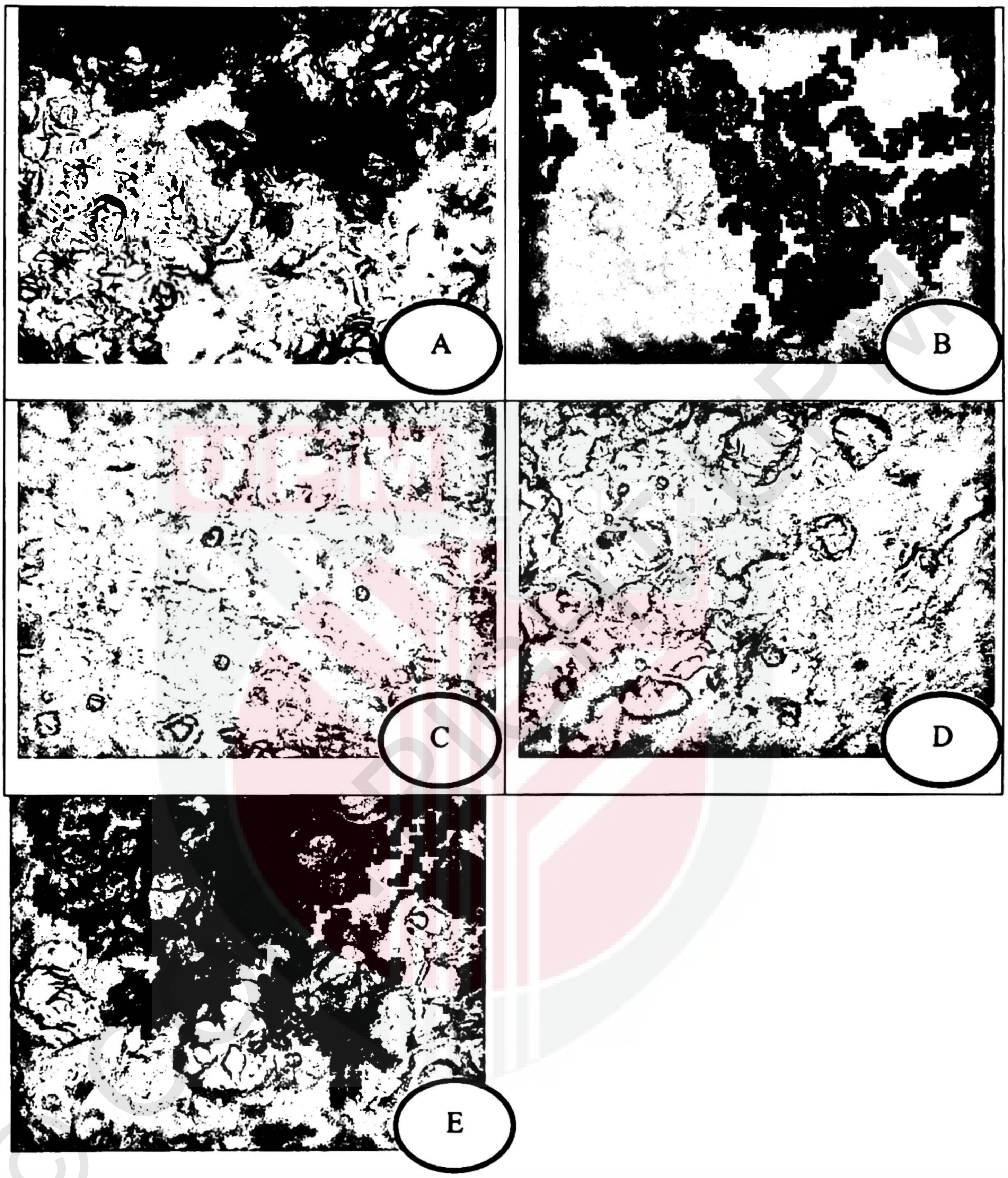

Figure 4. 11: Light Microscope photograph analysis of the surface morphology of the fried potato strips: For control (uncoated): A; 0.5wt% MC coating: B; 1.0wt% MC coating: C; 1.5wt% MC coating: D and 2.0wt% MC coating: E.

4.8.2. Image J analysis

Table 4. 4: Summary of the number of pores with the average of size formed in fried potato strip with controlled condition and coated with different concentration of Methylcellulose.

Methylcellulose Concentration	Pores no.	Total Area	Average Size
Control	867	25107	48.958
0.5wt%	526	24157	45.926
1.0wt%	379	10505	27.718
1.5wt%	653	31033	47.524
2.0wt%	606	30936	51.05

Based on the results of light microstructure photography, the pores numbers and sizes cannot be determined. Therefore, further analysis was carried on to provide stronger evidence for the discussion. Image j analysis can measure and determined the pores numbers and average sizes of pores available in the light microscope photography.

From table 4.4, we can see the average size of pores showed the smallest in 1.0wt% of Methylcellulose coated fried potato strip. The relationship of the pore sizes and the oil uptake are stronger based on the results which discussed in section 4.6. The results obtained are fitted with the relationship of the oil uptake and moisture loss of fried potato strips.

In short, image j analysis clearly showed the difference in pore sizes of varying concentration of methylcellulose as coating of fried potato strip. The pore sizes analysis is required to discuss for the mechanism of mass transfer during frying process of potato strips.

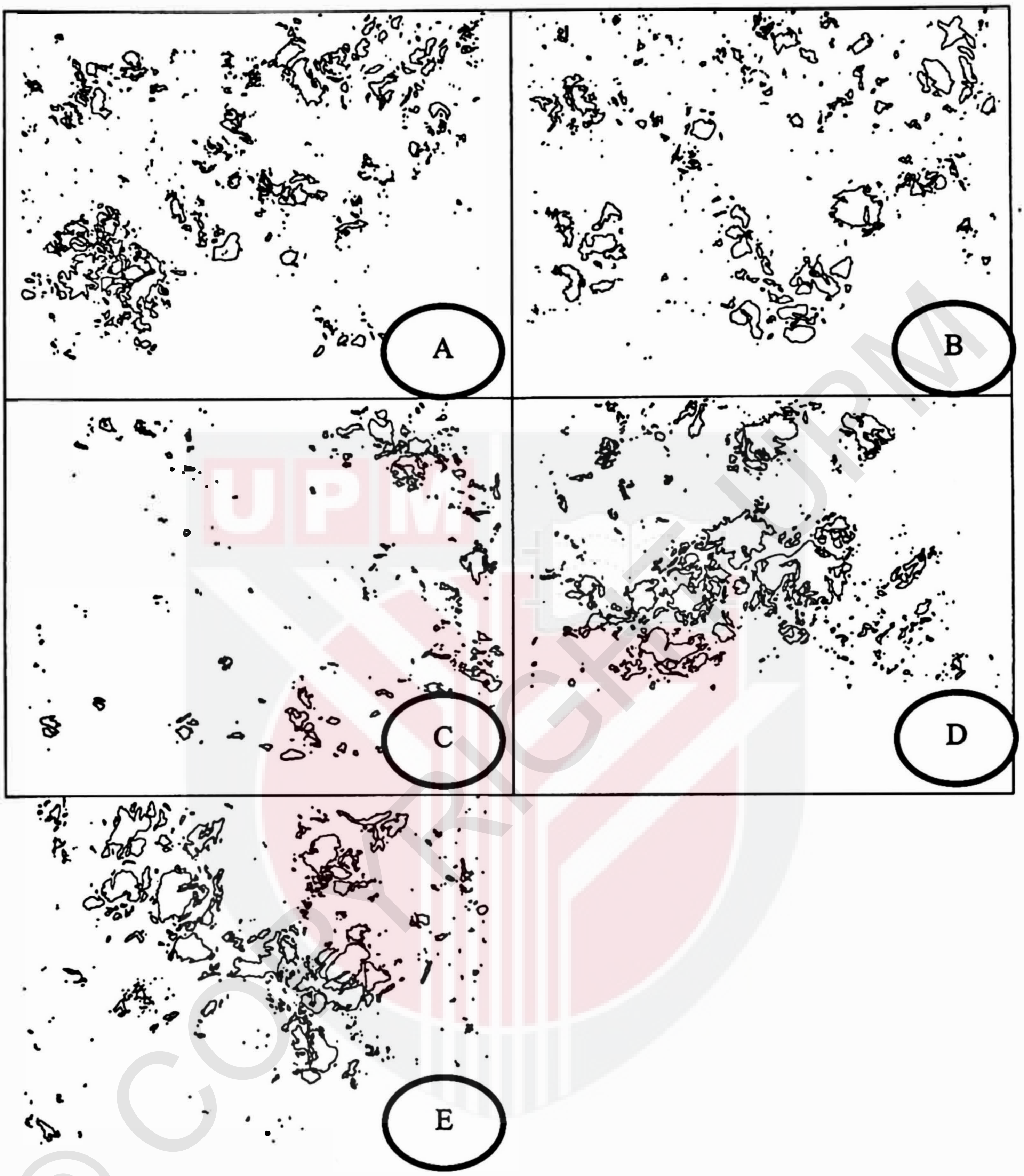

Figure 4. 12: Image J analysis for the surface morphology of the fried potato strips with bare outline: For control (uncoated): A; 0.5wt% MC coating: B; 1.0wt% MC coating: C; 1.5wt% MC coating: D and 2.0wt% MC coating: E.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATION

5.1. Conclusions

The effects of hydrocolloids (Methylcellulose) coatings on the moisture loss and oil uptake were investigates and correlated. It was found that the most effective coating formulation was 1.0wt% Methylcellulose for potato strips. In this formulation, oil uptake reduction was 44.38% and the water content retention after frying was 57.89%. This showed that the relationship of moisture loss is directly proportional to oil uptake in term of deep fat frying, which also related to the heat and mass transfer during the process. Whereas, the thermogelation properties of Methylcellulose work against moisture loss as we compared to the control sample (uncoated). It also results in lower oil absorption into the pores during frying process. On the other hands, the gelation time of the Methylcellulose showed the relationship between the oil uptake during frying process. As mentioned above, the use of 1.0wt% of Methylcellulose concentration was found to substantially reduce the oil content of the potato strips with high moisture retention as the gelation time is around 3minutes.

As a conclusion, the faster the gelation time of hydrocolloids formed, the stronger gel will obtain and where it might work as a barrier to moisture loss during frying process. This is a favourable result since our goal was to evaluate the effect of Methylcellulose coating formulation and the properties of Methylcellulose in term of the thermal reversible gelation mechanism on the oil uptake during deep fat frying.

5.2. Recommendation

Hydrocolloids have been widely used in fried products, especially in Europe country. Their widest application is as an oil absorption barrier and since the current study show the 1.0wt% of Methylcellulose (A4M) was the effective formulation for the potato strips as the one recommended in the finding of García et al. (2002). Therefore, further analysis can be carried on by investigating the frying method and the best formulation of Methylcellulose of air frying compared to deep fat frying for coated and uncoated fried potato strips. Besides, the comparison of commercial french fries with the coated potato strips in term of water retention and oil uptake during deep fat frying or air frying.

From the microscopic analysis, there is a probability of MC coating are having crack and break their microstructure with may affect the oil uptake during frying process. Plasticizer with the function to improve the flexibility of hydrocolloids solution can strengthen the structure of coating formed. So, determine suitable plasticizer with effective formulation can be carried out in the future study to improve and compare the reduction of oil uptake in fried potato strips.

Moreover, investigate the properties of methylcellulose with the additional of plasticizer should be done to relate to the oil reduction in fried product. As a conclusion, future research, especially on the heat transfer and mass transfer of the coated fried potatoes can continue to indicate the oil uptake mechanisms during frying process.

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APPENDICES

APPENDICES A

Appendices A. 1: Methylcellulose solutions with various concentration preparation

Appendices A. 2: Frying process of control and coating potatoes with different concentration

Appendices A. 3: Fried potatoes for deep-fat frying with control and coated conditions