CHARACTERIZATION OF PRODUCT QUALITY ATTRIBUTES AND THERMAL PROPERTIES OF POTATO CHIPS DURING VACUUM FRYING

A Thesis

by

CARLA VERONICA YAGUA OLIVARES

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2010

Major Subject: Biological and Agricultural Engineering

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Approved by:

Chair of Committee,	Rosana Moreira
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ABSTRACT

Characterization of Product Quality Attributes and Thermal Properties of Potato Chips during Vacuum Frying. (August 2010)

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Chair of Advisory Committee: Dr. Rosana Moreira

Vacuum frying is an alternative processing method for producing high quality snacks with the advantages of lower processing temperature, enhanced organoleptic quality, and reduced acrylamide content. Vacuum frying (1.33 kPa), with the aid of a de-oiling mechanism, was used to produce low-fat potato chips.

The kinetics of oil absorption and oil distribution in the potato chips (total, internal, and surface oil content) was studied so that effectiveness of the de-oiling system could be established. An analysis of product quality attributes (PQA) such as moisture content, oil content, microstructure, diameter shrinkage, and thickness expansion, as well as, bulk density, true density, and porosity of chips fried at different temperatures (120, 130, and 140°C) was performed in order to evaluate the effect of process temperature on the product. Moreover, heat capacity of the chips and convective heat transfer coefficient at the oil-chip interface were determined for the same temperature range.

The final oil content of the potato chips was 0.072±0.004, 0.062±0.003, and 0.059±0.003 g/g solid for frying temperatures of 120, 130, and 140ºC, respectively. These values are lower (80-85% less) than those found in traditionally-fried potato chip which indicates that the de-oiling mechanism is crucial in vacuum frying processing. A significant difference ($P<0.05$) was observed in oil content and oil distribution within temperatures. It was found that the rate of change in PQAs is greatly affected by temperature; however, the final values of moisture content, bulk density, true density, porosity, diameter shrinkage, and thickness expansion were not affected by temperature.

During vacuum frying, the specific heat of potato chips decreased with time as water decreases. The convective heat transfer coefficient changed considerably as frying progresses; moreover, it increased with temperature reaching a maximum between 2,200 and 2,650 W/m^2K depending on frying temperature.

DEDICATION

To my daughter, Veronica.

You are my strength, my inspiration, my joy, and my love.

ACKNOWLEDGEMENTS

I would like to thank Dr. Rosana Moreira, chair of my committee and academic advisor, for her guidance and help. Thanks for trusting in me. My gratitude extends to Dr. Elena Castell-Perez and Dr. Maria Barrufet, members of my committee, for their time and invaluable input. Thanks to Dr. Hung-Jue Sue for welcoming me in his lab and to Ivan and Minhao for your assistance during the DSC experiments. Thank you to Ann Ellis and Dr. Michael Pendleton for their technical assistance with the SEM for the microstructure analysis.

Special thanks to my parents, Doris and Carlos, for believing in me, their unconditional support, advice, and willingness to help in any possible way. To my husband, Marcos, thank you for your love, care, optimism, and never letting me fall. Thanks to my brother Carlos and my ‘sister’ Norma for being there for me when I needed it most.

Thanks Paulo for sharing your knowledge with me and being not only my lab tutor but my friend. Thanks to my friends at the Food Engineering Lab, Carmen, Mauricio, Yolanda, Ezekiel, Akhilesh, Taehoon, Isin, Alex, Dr. Kim, my for being my family away from home, and for all the laughs and great memories throughout the years. My sincere gratitude to all those people that were involved, directly or indirectly, in the completion of this thesis.

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CHAPTER I

INTRODUCTION

The most important attributes of fried food are texture, appearance and flavor. Potato chips are one of the most popular snacks in the United States and they have an oil content that ranges from 35.3% to 44.5% w.b. which gives the unique attributes combination that makes the chips desirable (Garayo & Moreira, 2002). In recent years, there has been an increased interest in reducing the amount of oil content of foods because of health concerns considering that the consumption of high fat food is a major cause for obesity. In addition, the potential production of acrylamide during the process of frying at high temperatures has been considered as a reason to reduce the consumption of deep-fat fried products. As a consequence, there is a demand for healthier food and a need for a cooking method that offers the same desired organoleptic characteristics of deep-fat frying processes without elevating the levels of fat consumption while minimizing acrylamide formation.

Frying under reduced pressure is an efficient alternative method of reducing the oil content in fried foods while producing potato chips with the same texture and color of those fried in atmospheric conditions (Da Silva & Moreira, 2008; Garayo & Moreira, 2002), as well as, lower acrylamide content (Granda et al., 2004) and enhanced organoleptic and nutritional qualities (Da Silva and Moreira, 2008; Shyu and Hwang,

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This thesis follows the style of the *Journal of Food Engineering*.

2001). Also, several studies have shown that less oil is absorbed during the vacuum frying process using different pretreatments and de-oiling steps (Garayo and Moreira, 2002; Moreira et al., 2009; Mariscal and Bouchon, 2008; Troncoso and Pedreschi, 2009).

Although there is literature concerning the feasibility and advantages of the vacuum frying process, and some studies in quality attributes of the final product, research on vacuum frying is at the initial stages since the process has not been fully understood. There is a need to understand and characterize the transport processes that occur during vacuum frying, as well as to determine physical and thermal properties that can be used to develop a mathematical model of the process, in order to optimize its application and to predict quality changes. Hence, the objectives of this study are as follows:

- Characterize product quality attributes such as oil content, microstructure, shrinkage, and expansion of potato chips during vacuum frying at different frying temperatures.
- Measure physical and thermal properties including bulk density, solid density, porosity, heat capacity, and heat transfer coefficient at different frying temperatures.

CHAPTER II

LITERATURE REVIEW

2.1. Potato chips

2.1.1. Raw material

The potato (*Solanum tuberosum*) is the world's fourth most important food crop, after maize, rice and wheat, with more than 323 million tonnes produced in 2007 (FAOSTAT, 2007).

The composition of potatoes is affected by several factor including variety, location of growth, maturity at harvest, and storage history. The two major components of potatoes are starch and water, with an average of 19.4 and 77.5%, respectively. The main two components of starch are amylose (15-21%) and amylopectin (79-85%). The average values of the major components of potatoes are summarized in Table 1-1.

Table 1-1. Chemical composition of potato tubers (Smith, 1977).

Component	Average value (kg/kg potato)	Range (kg/kg potato)
Water	0.775	0.632 – 0.869
Total solids	0.225	0.131 – 0.368
Carbohydrate	0.194	0.133 – 0.305
Fiber	0.006	0.0017 – 0.0348
Protein	0.02	0.007 – 0.046
Fat	0.001	0.0002 – 0.0096
Ash	0.01	0.0044 – 0.019

One of the important varietal characteristics of potatoes is maturity; early varieties are generally produced for the table potato market, while late varieties which are high in starch content are destined for processing (Lisinka and Lescszynski, 1989). Potato tubers high in dry matter are more suitable for potato chipping. Cultural, environmental and storage factors modify the genetic control of dry matter content. Storage of potatoes before processing is usually done at 7.2- 10°C, since cooler temperatures might cause conversion of starch to reducing sugars.

There are hundreds of wild potato varieties and some processing companies have invested significant effort and resources to breed and select improved potato varieties. The Atlantic variety is the standard for chipping since it has high dry matter content. However, this variety appears to be in decline, supplanted mainly by Frito-Lay varieties (Vreugdenhil et al., 2007).

2.1.2. Production and consumption

In the United States, 126 pounds of potatoes are consumed in a per capita basis. Fried potato products account for a large portion of the total potato crop utilization. The main uses of processed potatoes includes table stock (26%), frozen French fries (32%), chips and shoestrings (12%), and dehydrated items (10%) (USDA-NAAS, 2009).

Potato slices for chips are commonly cut thin (1.27-1.78 mm thick) and fried until the water content is reduced from 75-80% to 1-2% wet basis (Miranda and Aguilera, 2006). Potato chips can be grouped in two types: regular potato chips and fabricated or processed potato chips. The majority of chips are regular potato chips made from whole fresh or stored potatoes and fried in some kind of vegetable oil. Processed potato chips are made from potato flakes and are mostly used in baked chips; these products have had an increase in popularity on the potato chips market since they usually contain less fat.

Frito-Lay, Inc. dominates the world market for potato chips. Utilization of potatoes specifically for chips formed from the raw potato exceeds 3.5 million tonnes. When pre-formed potato products are included, i.e. Baked Lays®, Frito Lay's estimated potato usage for chips increases to 4 million tonnes, approximately half of the world total (Vreugdenhil et al., 2007).

2.2. Deep-fat frying

Deep-fat frying can be defined as a process of cooking food by immersing them in edible oil at a temperature above the boiling point of water, and therefore, may be classified as a dehydration process (Farkas, 1994). This process is one of the oldest and most common unit operations used in preparation of food. Today, numerous processed foods are deep-fat fried because of the unique flavor-texture combination imparted to the food (Varela, 1988).

During frying, heat transfer causes protein denaturization, starch gelatinization, water evaporation, crust formation and color development. Mass transfer is characterized by water and some soluble material escaping from the product during the process, combined with oil penetrating the food (Mil-Bel et al., 2009).

Deep-fat frying can be accomplished under three different pressure conditions: atmospheric pressure, low pressure (vacuum), and high pressure (Moreira et al., 1999). Under atmospheric pressure, deep-fat frying is commonly performed at temperatures ranging between 130 and 190°C. The high temperatures of the frying oil lead to the evaporation of water at the surface of the food, inducing crust formation (Bouchon, 2009). Also, oil is absorbed by the food, replacing part of the water.

In high pressure frying, vapor naturally released from the products generates pressure inside a closed vessel (Erdogdu and Dejmek, 2010). High pressure fryers are mainly used in the fried chicken industry because of the uniform color and high moisture content conferred to products; also, pressure fryers may reduce frying time (Bouchon, 2009). A disadvantage of this type of frying is that the frying oil degrades faster since steam from the food is retained within the fryer thus increasing buildup of free fatty acids (Garayo, 2001).

Vacuum frying consists in a deep-fat frying process carried out in a closed system under well below atmospheric levels, making it possible to reduce the frying temperature due to depression of the boiling point of water (Bouchon, 2009).

2.3. Vacuum frying

Vacuum frying is a technology that can be used to process value-added fruits and vegetables, with the necessary degree of dehydration and without excessive darkening or scorching of the product. In vacuum frying operations, food is heated under reduced pressure, preferably below 6.65kPa, causing a reduction in the boiling points of the oil and the moisture in the foods. (Shyu et al., 1998).

Garayo and Moreira (2002) developed a laboratory-scaled vacuum frying system to produce and study potato chips and other similar products. They study the effect of pressure and oil temperature in the product's oil content, texture, and color, and found that vacuum frying produce potato chips with 30% less oil content and similar texture and color characteristics of those made by traditional frying. Granda et al. (2004) demonstrated that potato chips fried under vacuum have 97% less acrylamide content than the traditionally fried chips.

Vacuum frying has also been used to process other fruits and vegetables. Quality product attributes (color, texture, phytochemicals, oil content and sensory characteristics) for sweet potato, blue potato, mango, and green beans fried under vacuum were evaluated by Da Silva and Moreira (2008); it was concluded from this study that vacuum-fried snacks retain more of their natural colors and flavors due to less oxidation and lower frying temperature. Shyu & Hwang (2001) studied the influence of processing conditions in apple slices fried under vacuum; Dueik et al. (2010) analyzed the characteristics of carrot chips during vacuum frying and found that vacuum-fried carrot crisps absorb 50.5% less oil than atmospheric fried ones at 80°C.

Vacuum fryers are commercially available for batch and continuous applications. The very first continuous vacuum fryer was developed in Europe by Florigo Inc., The Netherland. It was developed in the 1970s for producing high quality french fries. Today, the capacity of a vacuum fryer ranges from 350 kg/hour to 1500 kg/hour and it is mainly used for non blanched products (Pandey, 2009).

2.4. Product quality attributes

2.4.1. Oil content

Oil content is one of the main quality parameters for the French fry and potato chip industry. Some of the parameters affecting the final oil content of fried products are product shape, temperature and frying time, moisture content, porosity, pore size distribution, and pre and post treatments. (Bouchon and Aguilera, 2001; Moreira et al., 1997; Saguy and Pinthus, 1995).

Oil uptake is essentially a surface-related phenomenon resulting from the competition between drainage and suction into the porous crust once the potato is removed from the frying oil and starts cooling (Bouchon and Pyle, 2005a, 2005b; Gamble and Rice, 1987; 2003; Moreira et al., 1997). Vertical placement and centrifugation are two methods of oil removal in fried products before the cooling period. Vertical placement is used commercially and mechanical means are employed in order to place to chips in the desired angle. During centrifugation, the centrifugal force acts perpendicular to the surface of the chips and separates the oil directly from the porous surface (Pandey, 2009).

Moreira and Barrufet (1998) proposed that the oil uptake by tortilla chips can be described in terms of capillary forces and described the mechanism of oil uptake using the percolation theory. Kawas (2002) found that the pore size distribution developed during frying of tortilla chips is an important factor for oil absorption during the cooling period, since small pores formed in the chips trapped more air during frying, resulting in higher capillary pressure during cooling and, as a consequence, higher internal oil content.

The total oil content of fried products can be separated into two regions: the oil on the core of the product (internal oil) that is absorbed during frying, and the surface oil which is absorbed during cooling. Moreira et al. (1997) measured oil content on the surface (surface oil) and the core (internal oil) of tortilla chips to determine oil distribution during frying and cooling. The surface oil was extracted by dipping the tortilla chips for 1 second in a beaker with petroleum ether immediately after frying. The petroleum ether was evaporated and the oil left on the beaker was defined as surface oil. It was observed that only 20% of the oil content was absorbed during frying and 80% of the total oil content was surface oil.

Several studies have shown that less oil is absorbed during the vacuum frying process using different pre-treatment and de-oiling steps (Garayo and Moreira, 2002; Mariscal and Bouchon, 2008; Moreira et al., 2009). In addition, Troncoso and Pedreschi (2009) described the kinetics of water loss and oil uptake during frying vacuum frying of pre-treated potato slices; the water loss was explained using two models based on Fick's law of diffusion, and an empirical model was used for oil uptake. The finding of this study was that oil absorption at the surface increases during vacuum frying processes because of the higher heat and mass transfer rates and the existence of a pressurization step, thus increasing the final oil content compared to traditional frying for the same working temperature.

The pressurization process plays an important role in the oil absorption mechanism. It can increase or decrease oil absorption depending on the amount of surface oil and free water present in the product (Garayo and Moreira, 2002). Furthermore, Moreira et al. (2009) considered the amount of surface oil present at the moment of pressurization as a determining aspect for the final oil content of the product, and established that a de-oiling process must be used to remove surface oil under vacuum after the product is fried. They determined the internal and structural oil absorption kinetics during vacuum frying of potato chips, and found that 14% of the total oil content was located in the core (internal oil) and the remaining 86% of the oil content was surface oil. The de-oiling mechanism (centrifuging system) used in the study removed surface oil before the pressurization step and was able to reduce the total oil content from 80 to 90%.

In order to understand and decrease oil absorption during the pressurization step, Mir-Bel et al. (2009) investigated the influence of various parameters of the pressurization and cooling stage on the final oil content of fried potato using different geometries, and explained that oil absorption during the cooling stage is greatly influenced not only by the difference in temperature, but also by the vacuum break conditions as the system is restored to atmospheric pressure. They found that the volume of oil absorbed by the product is inversely proportional to the pressurization velocity meaning that lower velocities favors oil absorption showing an increase of 70% for potato chips compared to the oil content when the vacuum breaks abruptly.

There are different methods to determine oil content in foodstuff; the most common are extraction, hydraulic press, and Near Infrared Reflectance (NIR) spectroscopy (Moreira et al., 1999). Extraction is a separation method that consists of using an oil solvent such as petroleum ether, hexane, acetone, methanol, chloroform, and diethyl ether to separate the oil from the product (AACC, 1986). In the hydraulic press method, oil is separated from the product by pressing the sample with a hydraulic system. The NIR spectroscopy method is based on the property of the chemical bonds to absorb energy; the amount of energy that is reflected by the bonds depends on the quantity and type of functional groups present in the sample (Moreira et al., 1999).

Several studies on modeling the frying process, mainly focused on oil absorption (Bouchon and Pyle, 2005a, 2005b; Halder et al., 2007a, 2007b; Moreira and Barrufet, 1998) have been published; however none of these studies characterize the behavior of frying under vacuum since the physical and thermal parameters associated with oil absorption needed for modeling of this process have not been determined.

2.4.2. True density

True density is the weight of the material per unit of true volume (kg/m^3). True volume is the volume of the material including liquids (Kawas, 2000), where all the volume of open and closed pores is excluded. A gas pycnometer, an apparatus that uses gas displacement, is generally employ to determine true density of materials given that the gas used is capable of penetrating all open pores up to the size of the gas (usually helium) molecule.

2.4.3. Bulk density

Bulk density is the mass per unit bulk volume (kg/m^3), so it includes the air within the sample. Bulk volume in food can be difficult to calculate by its own geometrical characteristics since foods are usually irregular in shape (Kawas, 2000). Bulk volume of irregularly shaped materials can be measured by volumetric displacement of glass beads (Marousis and Saravacos, 1990), and by using liquid displacement with toluene (Costa et al., 2001; Lozano et al. 1983) or a water-ethanol mixture (Da Silva and Moreira, 2008; Nunes and Moreira, 2009).

Moreira et al. (1995) determined bulk density of tortilla chips during traditional frying using the volume displacement technique with amaranth seeds. It was found that bulk density decreased from 880 kg/m^3 before frying to 579 kg/m^3 after frying for 60 s.

2.4.4. Porosity

Porosity is a global characteristic of pores, which provides the volume fraction of total pores compared with the total volume of sample (Rahman, 1995). During frying, liquid water moves from inside of the chips to the evaporation zone leaving the product through the surface as vapor. Some of the vapor remains trapped within the pores of the material due to restrictive intercellular diffusion. The vapor in this confined space will expand and become superheated, distorting the pore walls and contributing for the chips porosity (Moreira et al., 1994).

Moreira et al. (2009) studied the porosity of vacuum-fried potato chips in order to evaluate the effect of a de-oiling process (centrifuge system) on this variable. The centrifuged chips had higher porosity (0.62) than the non-centrifuged ones (0.35) because of their lower oil content. The authors also found that porosity increased slightly with oil temperature, and that porosity rate has a similar behavior as the oil content rate during frying.

2.4.5. Microstructure

Starch granules are often considered as semi-crystalline biopolymer entities where water molecules form an integral component of the crystalline domains. The ordered granule structure is disrupted by heating with water; this is known as gelatinization or melting (Parker and Ring, 2001). Almost any application of starch involves gelatinization the granule structure (Thiewes and Steeneken, 1997).

A characteristic of potato cells is the presence of a cell wall that limits the expansion of the cytoplasm. The outer layer of the cell wall is the middle lamella composed of pectic material that cements cell together and is dissolved during heating. Cells normally contain numerous starch granules (Miranda and Aguilera, 2006). Extracellular starch occurs when the cells rupture or disintegrate upon mechanical or thermal stress during processing. It has been postulated that cells in the crust shrink and their walls become wrinkled and convoluted around dehydrated gelled starch but are not ruptured (Spiruta and Mackey, 1961).

The frying process involves simultaneous heat and mass transfer that causes significant microstructural changes to both the surface and the body of the product. Gamble et al. (1987) examined the microstructure of potato chips using light microscopy. Sections of the chips were cut in a cryostatic cabinet operating at -20°C and then stained the samples with iodine vapor, osmic acid vapor or an alcoholic solution of the lipid selective stain Oil Red O. They found that the cooked potato slices have gelatinized starch bags filling the softened potato cells.

The microstructural changes that occur during frying have been studied by different microscopy techniques including, light microscopy, confocal laser scanning microscopy (CLSM), and scanning electron microscopy (SEM). It has been found that swollen starch granules remain as a compact mass pressing on the outer wall before becoming dehydrated and that cells heated in oil stay intact and decrease slightly in area without any evidence of oil in their interior (Bouchon and Aguilera, 2001; Aguilera et al., 2001). Moreover, Pedreschi et al. (1999) demonstrated, using CLSM, that oil is placed as an egg-box arrangement surrounding intact potato cells.

Aguilera et al. (2001) studied the microstructural changes of potato cells and starch granules heated in oil and found that starch granules ranged in size from 5 to 60µm, and that swelling started between 3 and 5 s after immersion in oil and was completed in less than 2 s. Also, integrity of cell walls and the presence of a dense starchy interior supported the idea that oil cannot penetrate into the cells during frying.

2.4.6. Diameter shrinkage and thickness expansion

Changes in diameter and thickness during frying of foodstuff are usually referred as diameter shrinkage and thickness expansion, and are defined as the ratio of the dimension difference of the sample before and after drying and the initial dimension.

Shrinkage of biological materials during drying takes place simultaneously with moisture diffusion and thus may affect the moisture removal rate. During the early stages of frying, the amount of shrinkage bears a simple relationship to the amount of water removed, whereas at the end of frying, the rate of shrinkage is reduced and the final shape and size of the material are fixed before frying is complete. The change in volume during drying is not an easily predictable function since, in addition to shrinkage due to the loss of water, air-filled pores are formed which result in a smaller change in volume than that expected for a nonporous material (Wang and Brennan, 1995).

Moreover, the rate of volume change is greater for the higher processing temperature, but potato chips processed at lower temperature result in highest final value of volume shrinkage. This is due to the fact that higher temperature causes the sample surface to become rigid faster, thus producing increased resistance to volume change (Caixeta et al., 2002).

A comparison of the volume shrinkage between chips fried under vacuum and at atmospheric pressure was made by Garayo and Moreira (2002). It was found that the final shrinkage in volume of potato slices decreases as oil temperature increases; this behavior is believed to occur since the surface of the potato becomes rigid more rapidly at higher oil temperatures, thus producing increased resistance in volume change. They also observed that vacuum fried slices have less expansion and numerous small bubbles as opposed to slices fried at atmospheric pressure which have more expansion and lesser but larger bubbles. Volume shrinkage depends on water transfer within the product and bubble formation at the surface of the product results from gas expansion inside the pores.

Kawas and Moreira (2001) measured diameter shrinkage and thickness expansion during frying of tortilla chips. It was observed that the final diameter shrinkage for chips fried at 190°C shrank more than those fried at 160°C (9.4% and 7.5%, respectively). In addition, the degree of thickness expansion increases significantly (10% at 190°C) after the first 30 s of frying and that expansion increases with oil temperature.

The effect of a centrifuge de-oiling system on the diameter shrinkage of potato slices during vacuum frying was investigated by Moreira et al. (2009). They found that diameter shrinkage increases with time and temperature of frying (10.0% at 120°C), but there were no significant differences ($P<0.05$) in diameter between the centrifuged samples and the non-centrifuged ones.

2.5. Thermal properties

2.5.1. Specific heat capacity

The specific heat capacity is a characteristic material property. It describes the amount of heat required to increase the temperature of the material by 1 K at constant pressure, and hence it is an important property for the calculation of thermal processes.

Some equations to calculate heat capacity, based on the composition and specific heat of the components of the food material, have been proposed (Choi and Okos, 1986; Heldman and Singh, 1981; Riedel, 1978). Equations to predict specific heat based on the composition and state of the material provide a useful tool in the absence of experimental data, nevertheless thermal properties can be under or over-estimated by such approach, because of the possibility of component interactions with each other exists (Njie et al., 1998). Mohsenin (1980) and Sweat (1986) state that the composition based equations give reasonable estimates of specific heat for material with high water content, but give a lower value than experimental for lower moisture materials.

Measurement of heat capacity has been done with an adiabatic calorimeter, where the stepwise temperature changes of an internally heated calorimeter in controlled, adiabatic surroundings, were followed (Wunderlich et al., 1997). Advances in modern control and measurement technology have allowed the developed of differential scanning calorimeters (DSC), that permits the measurement of materials in a continuous scanning mode (Tan et al., 2004).

Moreira et al. (1995) studied the specific heat capacity of tortilla chips using differential scanning calorimetry. They found that specific heat capacity decreases from 3.36 kJ/kg°C before frying to 2.31 kJ/kg°C after frying for 60 s.

2.5.2. Convective heat transfer coefficient

During frying heat is transferred from the oil to the surface of the product by convection and then from the surface to the center of the product by conduction, which causes an increase in temperature until the boiling temperature is attained and water starts evaporating (Farkas et al., 1996).

The deep-fat frying process at atmospheric pressure can be broken down into four stages: initial heating, surface boiling, falling rate, and bubble end point. Initial heating is described as the initial immersion of raw material into the oil and there is no water vaporization during this period; the surface boiling stage is characterized by sudden loss of free moisture at the surface and increased surface; the falling rate stage is where the thickening of the crust takes place, there is a decrease in heat transfer and a steady decrease of vapor loss; and during the bubble end point there is cessation of moisture loss from the food (Farkas et al., 1996). These four stages were further generalized by Hubbard and Farkas (1999) as non-boiling phase (initial heating and bubble end point) and boiling phase (surface boiling and falling rate).

Several authors have studied the convection heat transfer coefficient, *h*, between the oil and the surface of the product using direct and indirect measurement methods. The simplest, most convenient, and highly used method is the Lumped Capacitance Method (LCM) which consists of using a metal transducer, a high thermal conductivity material, placed inside the frying oil close the raw material, and the temperature of the oil and the center of the metal piece are recorded. Once the experimental data is collected, *h* is calculated from a surface energy balance equation with two assumptions: (i) steady-state conditions; (ii) the Biot number of the heated solid is less than one.

For the Biot number to be less than one, the resistance to conduction within the solid is much less than the resistance to convection across the fluid boundary layer (Incropera et al., 2006). Because of their low thermal conductivity, biological materials are unlikely to have Biot numbers less than one; Yildiz et al (2007) estimated that the Biot number for potato strips during frying ranged from 1.4 to 2.20 for frying temperatures between 150 and 190°C.

The convective heat transfer coefficients of four types of oils during frying of potato strips were determined by Miller et al. (1994) using an aluminum transducer, and the calculated values for fresh oil at 170°C were 249.5, 251.4, 261.3 and 265 W/m^2K for palm, canola, soybean and corn oils, respectively. Work done by Moreira et al. (1995)

focused on studying oil degradation during frying of tortilla chips and its effect on *h* also using the LCM; they obtained similar results showing that and that *h* of soybean oil decreases nonlinearly from 274 to 250 W/m^2K with degradation of oil. However, most of these works have focused on the non-boiling stage of frying and overlooked the influence of turbulence caused by escaping water vapor bubbles at the surface of the product.

Costa et al. (1999) compared the LCM with a direct method during frying of French fries and potato chips, the latter method does not requires a metal transducer; it measures the temperature of the product, and is based in an energy balance assuming that the total heat transferred by convection is used for heating the potato and water evaporation. The researchers found that the heat transfer coefficient determined in frying were up to two times greater than those obtained in the absence of vapor bubbling; also, they showed that the *h* calculated from the direct method, maximum of 600 W/m^2K for French fries at 140°C, are higher than those calculated with the LCM, maximum of 440 W/m^2K for the same conditions; suggesting that the latter method may underestimate the *h* values.

A procedure for determination of convective heat transfer coefficient for canola oil during the boiling phase of frying of potato cylinders was developed by Hubbard and Farkas (1999); they measured the drying rate of the material, surface area, oil temperature, and surface temperature of the product, and then calculated the heat transfer coefficient (300 to 1100 W/m^2K) using an energy balance on the cylinder, assuming no heat gradient on the core of the potato.

Using the previous approach, Budzaki and Seruga (2004) determined the convective heat transfer coefficient of potato dough balls during deep fat-frying in soybean oil, which ranged from 94.22 to 774.88 W/m^2K, and evaluated the influence of oil temperature (160 to 190°C), water migration and surface temperature. Their results are in accordance with previous studies where the convective heat transfer coefficient increases as oil temperature increases and at higher water migration rates. Erdogdu and Dejmek (2010) also used Hubbard and Farkas' (1999) method to estimate the *h* value during high pressure (200 kPa) frying of potato slabs in canola oil at 170°C; pressure frying was found to lead to higher heat transfer coefficient values.

CHAPTER III

MATERIALS AND METHODS

3.1. Raw material

Potatoes were provided by Frito-Lay North America, Inc. (Plano, Texas). After harvest, potatoes were stored in a refrigerator at 10°C and 95% relative humidity; they were left at room temperature for 3-4 days to allow reconditioning (specific gravity of 1.09±0.1) and to lower the reducing sugar content before processing.

3.2. Sample preparation

Potatoes were peeled and then sliced using a mandolin slicer (Matfer model 2000, France) to a thickness of 1.6 mm, measured with a thickness gage (Mitutoyo Thickness Gage, Japan), and cut to a diameter of 5.08 cm using a cylindrical metal cutter. The potato slices were rinsed in distilled water to eliminate starch material on the surface and then blotted with paper towels before each experiment. The samples were placed in aluminum foil to avoid any moisture loss before further processing.

3.3. Frying experiments

3.3.1. Vacuum frying experiments

The experiments were performed using a vacuum fryer available at the Food Engineering Laboratory, Department of Biological and Agricultural Engineering at Texas A&M University, College Station, Texas. The fryer consists of a cast aluminum vacuum vessel with a heating element. Inside the vessel, there is a basket and a centrifuging system (de-oiling system) with a maximum rotational speed of 750 rpm (63 g units). Vacuum is achieved in the vessel by a dual seal vacuum pump (model 1402 Welch Scientific Co., Skokie, IL) with a vacuum capacity of 1.33 kPa. The vacuum fryer system is depicted in Figure 3-1.

The frying process consists of loading 6 potato slices (about 25 g) into the basket, closing the lid, and depressurizing the vessel. Once the pressure in the vessel reaches 1.33 kPa, the basket was submerged into the oil. After 6 minutes of frying, the basket was raised, and the centrifuging system was applied for 40 s at maximum speed (750 rpm). Then, the vessel was pressurized and the potato chips were allowed to cool down at ambient temperature before storing then in polyethylene bags inside of a desiccator for further examination. This procedure was used for three different oil temperatures, 120, 130, and 140°C. Fresh canola oil (Crisco, Ohio, USA) was used in all experiments.

3.3.2. Traditional frying experiments

Frying at atmospheric pressure was performed on an electric-fired fryer (George Foreman GSF026B Deep Fryer with Smart Spin Technology) containing a centrifuging system (maximum rotational speed 350 rpm) with canola oil at 165ºC for 6 minutes. The frying process was similar to the one used in vacuum frying experiments, but with no depressurization step and at different centrifuge speed (350 rpm).

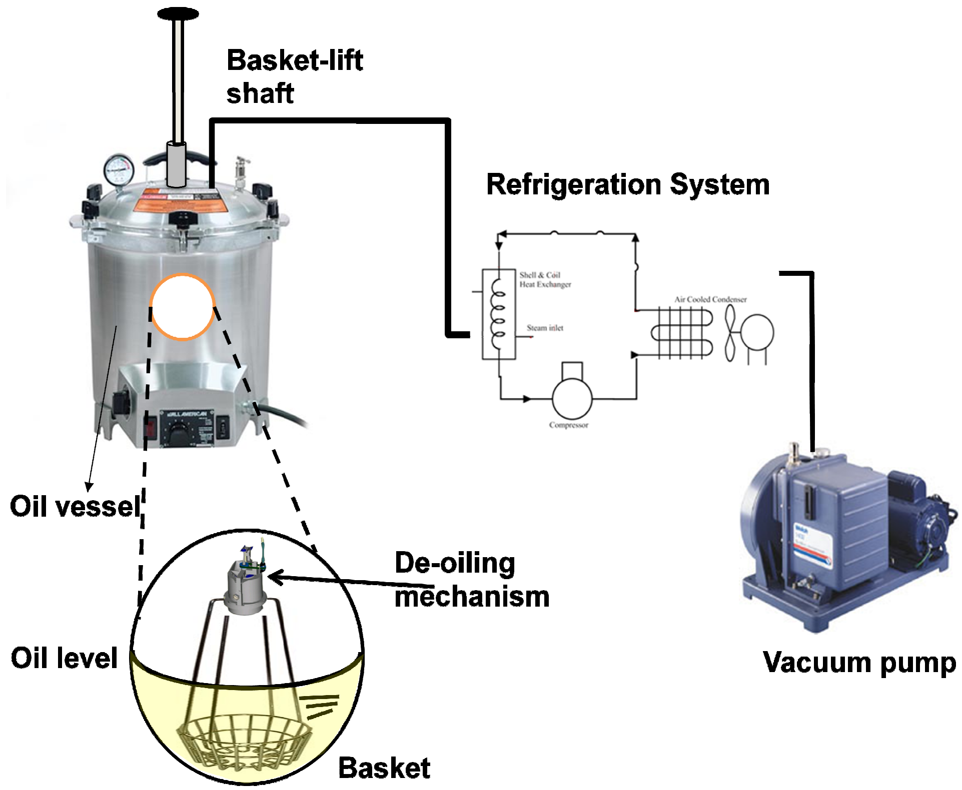


Figure 3-1. Vacuum frying system set-up. Adapted from Moreira (2008)

3.4. Data acquisition system

The changes in temperature and pressure of the vacuum system were recorded, to assure optimum performance during frying, using a data acquisition system (model OMB DAQ 54 Omega Engineering Inc., Stamford, CT, USA), that works on the principle of analog-to-digital conversion. A controller directly collects temperature and pressure data in the form of voltage through type-K thermocouples (Model KMQXL, Omega Engineering Inc., Stamford, CT, USA) and a pressure transducer (Model PX209-015G5V, Omega Engineering Inc., Stamford, CT, USA) placed inside the vacuum fryer. The variables measured by this system are temperature at the surface and at center of the potato chip, temperature of the vessel headspace, and pressure inside the vessel.

3.5. Product quality attributes (PQA)

3.5.1. Oil content

The Soxtec System HT extraction unit (Pertorp, Inc., Silver Spring, MD, USA) with petroleum ether as the solvent (AACC 1986) was used to determine the oil content of the samples. Potato chips were ground using a coffee grinder, and about 3 g of dried sample were placed on cellulose thimbles (model 2800256, Whatman, England) throughout the oil extraction.

Prior to starting the extraction, aluminum cups were dried for 15 min in a convection oven at 105^{o}C and cooled down in a desiccator for 25 min before recording the weight of the empty cups. The extraction process consisted in three steps. First, the thimbles with the sample were submerged in the cups into boiling petroleum ether for 40 min; then the thimbles were raised up to the rinsing position where they were washed with recirculating petroleum ether while oil was still being collected in the cups. The final step was to evaporate the petroleum ether from the cups and collect it. In order to ensure that all the petroleum ether was removed from the oil, the cups were placed in a convection oven at 105°C for 15 min and then cooled in a desiccator for 20 min. The cups with the oil were weighted and the oil content, *OC*, in wet basis (d.b.) of each sample was determined using the following equation.

$$OC(d.b.) = \frac{W_2 - W_1}{W_i} \qquad [3\text{-}1]$$

where W_1 (g) and W_2 (g) are the initial and the final cup weight, respectively; and W_i (g) is the dried weight of sample i.

Three types of oil were quantified: internal, surface, and total. Internal oil is found in the core of the product and is absorbed during frying; surface oil is absorbed during the pressurization step; and total oil is the sum of internal and surface oil. In this study, total oil (TOC) was defined as the oil content of the product after frying without any de-oiling process; internal oil (IOC) was defined as the oil content after the de-oiling process; and surface oil (SOC) was determined by subtracting the internal oil content from the total oil content. All tests were carried out in triplicate.

3.5.2. Moisture content

The moisture content of the potato chips was determined by weight loss after drying 3 g of ground sample in a forced convection oven at 105°C (AACC, 1986) for 72 h. The test was performed in triplicate. The weight of the sample was recorded before and after drying, and the moisture content, *MC*, in wet basis (w.b.) was calculated as follows:

$$MC(w.b.) = \frac{(M_{wet} - M_{dry})}{M_{wet}} \quad [3\text{-}2]$$

where M_{wet} (g) is weight of the wet sample and M_{dry} (g) is weight of the dry sample. The moisture content in dry basis (d.b.) was defined as:

$$MC(d.b.) = \frac{(M_{wet} - M_{dry})}{M_{dry}} \quad [3\text{-}3]$$

3.5.3. Bulk density

The bulk volume was measured using the liquid displacement technique with ethanol (Da Silva et al, 2008; Nunes and Moreira, 2009) using a solution of 10% ethanol. Five potato chips were weighed, and the volume in the apparatus was recorded with and without the sample. Bulk density was then determined by dividing the weight of the chips without oil (de-oiled) by its bulk volume. The weight of a de-oiled chip was calculated from the original weight of the chip and the oil content data. Bulk density, ρ_b, was determined using the following equation:

$$\rho_b = \frac{M_s}{V_b} \quad [3\text{-}4]$$

where M_s and V_b are the weight of the de-oiled sample (g) and bulk volume (m^3), respectively. The test was performed in triplicate.

3.5.4. True density

The true volume, defined as the volume occupied by solid matter and water, of approximately 1 g of ground samples of raw and fried potato slices without oil (de-oiled chips) was determined using a compressed helium gas multi-pycnometer (Quantachrome & Trade, NY, USA). The solid volume was determined by two pressure readings given by the pycnometer. Knowing the volume of the reference (V_r) and the cell (V_c), the solid volume (V_t) was calculated by:

$$V_t = V_c - V_r \cdot \left(\frac{P_1}{P_2} - 1\right) \quad [3\text{-}5]$$

where P_1 and P_2 are initial and final pressure given by the pycnometer, respectively; V_c is the volume of the sample cell, and V_r is the volume of the reference cell. The volumes of the sample and reference cell are constants obtained by previous calibration of the equipment; the values of V_c and V_r used in this study are 12.494 and 7.577, respectively. True density, ρ_t, was calculated using the following equation:

$$\rho_t = \frac{M_s}{V_t} \quad [3\text{-}6]$$

where M_s is the weight of the de-oiled sample (g) and V_t is the true volume of the sample (m^3). The test was performed in triplicate.

3.5.5. Porosity

The porosity, ϕ, of the potato chips was calculated as:

$$\phi = 1 - \frac{\rho_b}{\rho_t} \quad [3\text{-}7]$$

where ρ_b is bulk density and ρ_t is true density.

3.5.6. Microstructure

Photomicrographs of the structure of potato chips were taken in a JEOL JSM 6400 scanning electron microscope (JEOL USA, Peabody, MA) at the Microscopy and Imaging Center of Texas A&M. The microscope was operated at an accelerating voltage of 15 kV and 39 mm working distance. Each sample was divided into small pieces for surface and natural fracture views. Before taking the images, the potato slices (raw and fried) were chemically prepared in order to maintain the physical integrity throughout the imaging process. The preparation process was as follows.

The complete slices were placed in containers with 40 ml, enough to cover the sample, of fixative composed of 2.5% (vol/vol) glutaraldehyde and 1% (vol/vol) acrolein in 0.05M HEPES buffer, pH 7.5. Subsequent processing was done using cold microwave technology in a Biowave microwave (Ted Pella, Inc., Redding, CA). The samples submerged in fixative were placed in the microwave for 30 min with intermittent vacuum cycles (5 min ON and 5 min OFF). Primary fixation was finished at 10ºC by a 6 min microwave cycle (2 min ON; 2 min OFF; 2 min ON) at 200 W power and intermittent vacuum cycles (30 s ON and 30 s OFF).

The samples were washed three times for 1 min in the microwave at 200 W power with 0.05 M HEPES buffer, pH 7.3, followed by post fixation overnight in a solution containing 1% (vol/vol) osmium tetroxide – 1.5%(wt/vol) potassium ferricyanide, 0.05 M HEPES, pH 7.3. This process was terminated by a 6 min cycle (2 min ON; 2 min OFF; 2 min ON) in the microwave at 10 ºC and 100W. Specimens were then washed one time for 1 min at 200 W in the microwave with 0.05 M HEPES buffer, pH 7.3 and then dehydrated with ascending concentrations of methanol in 5% steps (vol/vol) from 5% - 45% at 1 min/step in the microwave at 10ºC and 200 W, from 50% - 100% at 6 min/step in the microwave at the same temperature and power conditions. Samples were rinsed with three times with hexamethyldisilazane (HMDS - Electron Microscopy Sciences, Hatfield, PA) in the microwave for 6 min each time at 200 W and then left to dry out under the hood for 6 hours..

Afterwards, small sections of the surface and a natural fracture of each sample were placed on aluminum stubs with carbon sticky tape and Electrodag 502 (Ted Pella, In., Redding, CA) and then sputter coated with carbon and with gold/palladium mixture (50/50) using a Hummer I Sputter Coater (Anatech Ltd., Union City, CA) with an on and off cycle for 20 min at 11 mV to produce an approximate 400 Å–thick coating. Samples were stored in a desiccator until observation in the microscope.

The samples were analyzed at different magnification (x100, x500, x1000) and best images were recorded. The selection criteria for best image depended upon the pore size distribution, structural discontinuities, and deterioration of starch from frying.

3.5.7. Diameter shrinkage and thickness expansion

The diameter and thickness of raw and fried potato slices was measured using a steel caliper (MG Tool Co., New York, NY, USA). Four slices and four readings per slice were recorded for each treatment.

The degree of diameter shrinkage, *D*, was calculated by:

$$D = \frac{d_o - d(t)}{d_o} \times 100 \qquad [3\text{-}8]$$

where d_o is the initial diameter of the raw sample (m) and $d(t)$ is the diameter of the sample at frying time t (m).

The degree of thickness expansion, *L*, was calculated by:

$$L = \frac{l(t) - l_o}{l_o} \times 100 \qquad [3\text{-}9]$$

where l_o is the initial thickness of the raw sample (m) and $l(t)$ is the thickness of the sample at frying time t (m).

3.6. Thermal properties

3.6.1. Specific heat

The specific heat of raw and vacuum-fried potato slices, with different moisture content, was determined using a Differential Scanning Calorimeter (Model 821, Mettler-Toledo, Switzerland) at a temperature range from 25°C to 80°C with a scan rate of 10°C/min. About 15 mg of grounded and homogenized sample was placed into aluminum crucibles (Model ME-51119810, Mettler-Toledo, Switzerland), which were then sealed using an encapsulation press. Temperature and heat flow data were recorded using the DSC equipment analysis software STARe.

Experiments were performed running two crucibles at the same conditions: the measuring crucible, containing the sample, and the reference crucible. Tests were carried out in triplicates. The specific heat, C_p, of the sample was calculated by:

$$C_p = \frac{dH}{dt} \cdot \frac{1}{Q \cdot M_i} \qquad [3\text{-}10]$$

where dH/dt is the enthalpy change with respect to time (J/kg·s), Q is the heating rate (ºC/s), and M_i is the mass of sample i (m).

The specific heat of the samples was also estimated using two correlations found in the literature. The first model was proposed by Riedel (1978) for predicting the specific heat of eight different foods, including potato starch, as a function of temperature and moisture content.

$$C_p = 4.187[x_w + (\alpha + 0.001T)(1 - x_w) - \beta \exp(-43x_w^{2.3})] \qquad [3\text{-}11]$$

where x_w is the mass fraction of water, T is temperature (ºC), α and β are constants reported by Riedel to be 0.34 and 0.06, respectively, for potato starch.

The second model is an empirical equation, based on the composition and the specific heat of the individual components of the sample, proposed by Heldman and Singh (1981).

$$C_p = 1.424x_c + 1.675x_f + 4.187x_w \qquad [3\text{-}12]$$

where x_c, x_f, x_a, and x_w are the mass fractions of carbohydrate, fat, air, and water, respectively.

3.6.2. Convective heat transfer coefficient

The convective heat transfer coefficient, h, between the oil and the surface of the product during the boiling phase of frying, was calculated using the formula suggested by Hubbard and Farkas (1999).

$$h = \frac{dm}{dt} \cdot \frac{\Delta H_{vap}}{A(T_o - T_S(t))} \qquad [3\text{-}13]$$

where dm/dt is the drying rate (g/s), ΔH_{vap} is the heat of vaporization of water (J/kg), A is the surface area of the chip (m^2), T_o is the temperature of the oil (ºC), and T_S is the temperature at the chip-oil interface at time t (ºC).

The heat of vaporization of water, ΔH_{vap}, was assumed to be constant for the duration of the frying process. From saturated steam tables (Incropera, 2006), the ΔH_{vap} is 2,473 kJ/kg at a pressure of 1.33 kPa.

Temperature at the chip-oil interface, T_S, was recorded during the complete frying process by means of a 0.254-mm diameter thermocouple (Model KMQSS, Omega Engineering Inc., Stamford, CT, USA) placed slightly below the surface of the potato chip. Triplicate runs were performed and the average values were recorded. Variations in oil temperature, T_o, were negligible, hence T_o was assumed to remain constant during the frying period for the three different frying temperatures (120, 130 and 140°C).

The moisture loss of a potato chip during the process was determined from the moisture content data at different frying times. Then, this data was fitted to a nonlinear polynomial equation as a function of frying time. Afterwards, the derivative of the polynomial equation was used to calculate the drying rate, *dm/dt*.

The surface area of the sample, A, was calculated from the data obtained in the diameter variation experiment. The chip was considered an infinite plate and the equation used to calculate the surface area was:

$$A = \pi(r(t))^2 \qquad [3\text{-}14]$$

where $r(t)$ is the radius of the potato chip at time t.

3.7. Statistical analysis

The data were analyzed using SPSS software (version 18.0 for Windows, 2009). Determination of linear and non-linear regression parameters was conducted using the Levenberg-Marquardt algorithm in the statistical software SPSS. The statistical study consisted of one-way analysis of variance (ANOVA) and Duncan's multiple range tests. Statistical significance was expressed at the $P<0.05$ level.

CHAPTER IV

RESULTS AND DISCUSSION

4.1. Effect of oil temperature and frying time on temperature and pressure history during vacuum frying of potato chips

The history of temperature at the center of the potato chip (*PC*), temperature of the vacuum vessel headspace (*HS*), and temperature at the surface of the chip (*PS*), as well as the pressure history (*P*) during the frying process at different temperatures, are represented in Figure 4-1, Figure 4-2, and Figure 4-3, for frying temperatures of 120, 130, and 140°C, respectively.

The vacuum frying process can be divided into four periods: depressurization (DP), frying (FR), pressurization (PR), and cooling (CL). During the depressurization period, the potato slices are placed in the headspace of the frying vessel and waiting for the pressure value to go down to 1.33 kPa in order to start the second period; depressurization of the vessel takes approximately 90 to 100 seconds. The next step, immersion frying, is performed for six minutes at each specific temperature (120, 130, and 140°C for this study). During this step, heat and mass transfer phenomena occur; heat is convected from the oil to the surface of the product and then conducted from the surface to the center of the product, water is evaporated from the potato and a small amount of oil is absorbed by the chip. After frying has been completed, the chips are taken out of the frying medium and held up in the vessel headspace while the vacuum is broken and the system recovers up to atmospheric pressure which is achieved in about one minute; an initial cooling of the product also occurs in this stage. Once the system is back to atmospheric pressure, the chips are removed from the frying vessel and allowed to cool down to ambient temperature. As the potato chips cool, during the pressurization and cooling steps, the pressure inside the pores changes, thus creating a differential in pressure, ΔP, between the surface and the center of the product. This pressure difference generates a driving force for the oil at the surface to penetrate the pores. However, the ΔP during the cooling period is much smaller than the one during the pressurization period.

4.1.1. Temperature at the center of the chip (*PC*)

A fine thermocouple (0.254-mm diameter) was placed at the center of a potato slice of 1.6 mm thickness and 25.4 mm in diameter in order to study the temperature history during the vacuum frying process at various temperatures (Figures 4-1 to 4-3).

It was noted that at all frying temperatures, temperature at the center of the potato has a subtle increase followed by a slight decrease during the depressurization period. The increase in temperature takes place when the potato is in the headspace of the vacuum vessel where the temperature is high (80-90ºC) due to heat irradiating from the oil (See Section 4.1.3.); while the decrease in temperature is a consequence of lowering the pressure of the system, since the potato chip is trying to reach the saturation temperature at the new pressure.

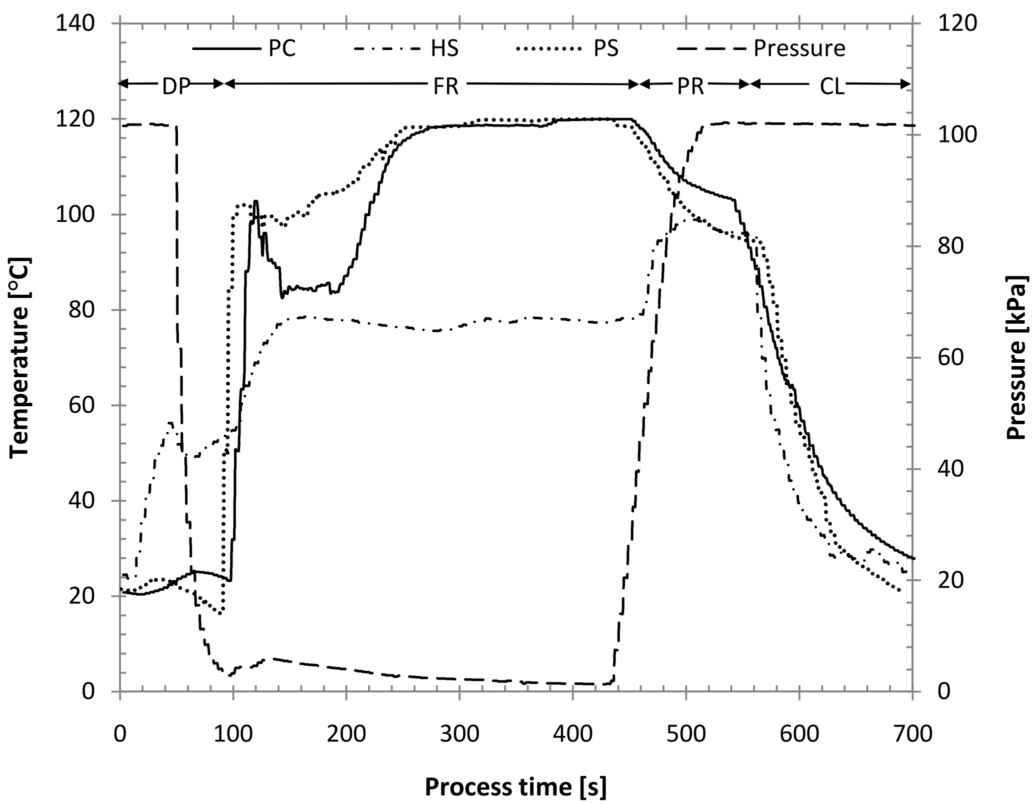


Figure 4-1. Temperature history for temperature at the center of the potato chip (PC), temperature of the vacuum vessel headspace (HS), and temperature at the surface of the chip (PS), as well as the pressure history (P) during the frying process for an oil temperature of 120 ºC.

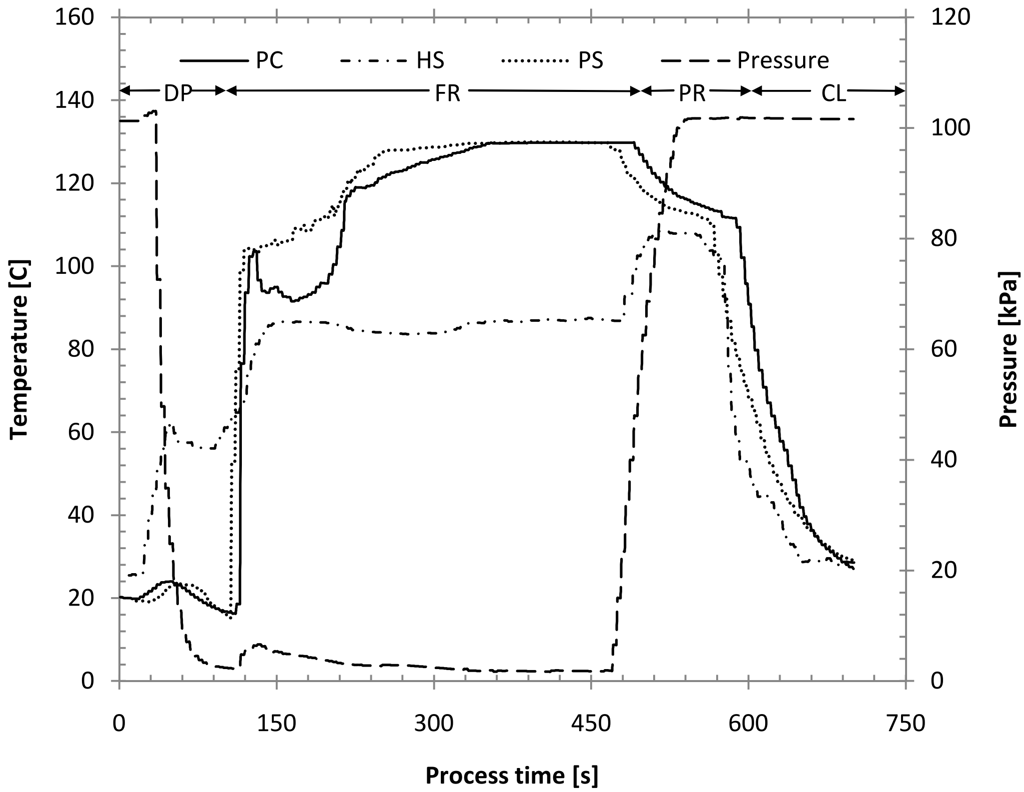


Figure 4-2. Temperature history for temperature at the center of the potato chip (PC), temperature of the vacuum vessel headspace (HS), and temperature at the surface of the chip (PS), as well as the pressure history (P) during the frying process for an oil temperature of 130ºC.

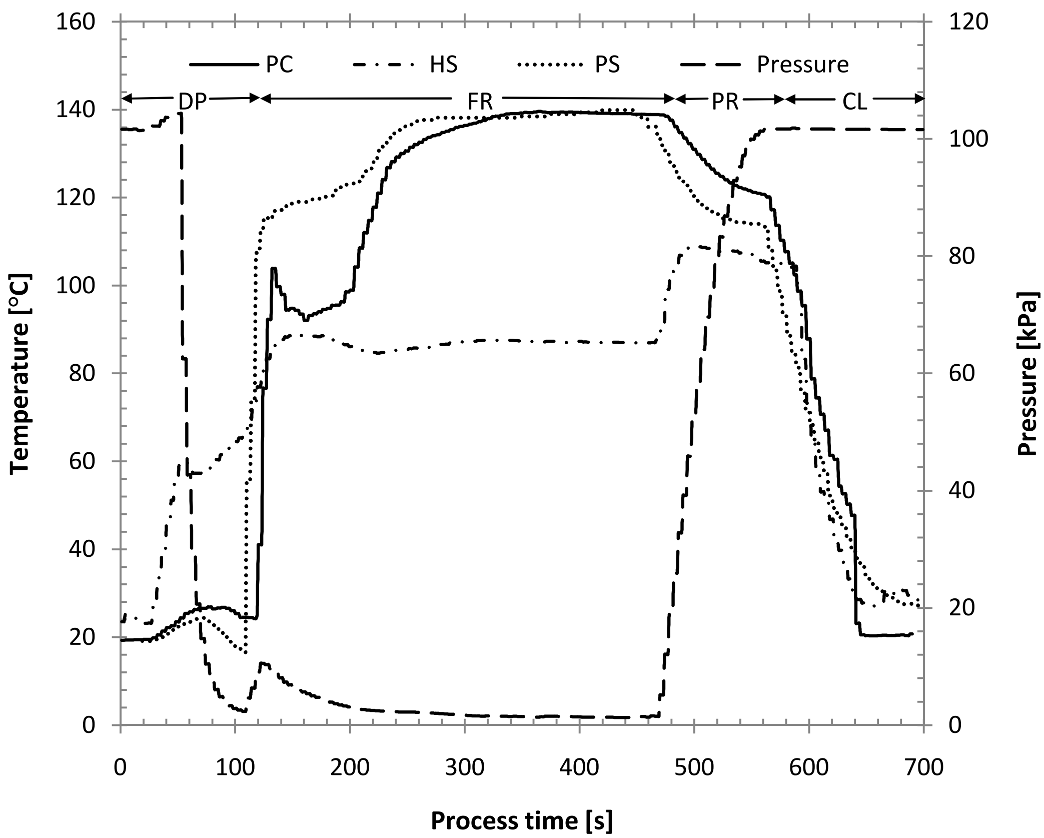


Figure 4-3. Temperature history for temperature at the center of the potato chip (PC), temperature of the vacuum vessel headspace (HS), and temperature at the surface of the chip (PS), as well as the pressure history (P) during the frying process for an oil temperature of 140ºC.

Once immersed in the oil, the temperature of the potato chip increased drastically and a temperature spike up to 104°C was observed (Figure 4-1) during the first 10-15 seconds of frying, after this, the temperature starts lowering until it reaches a plateau which is known as the evaporation period. Water evaporated for a longer period of time when frying at the lowest temperature (120ºC); the length of the evaporation period was 70, 65, and 60 seconds corresponding to the frying temperatures of 120, 130, and 140°C, respectively. An interesting finding was that the evaporation temperature of water was between 86 and 94°C depending on the frying temperature. This evaporation temperature is well above the water evaporation temperature at the system pressure of 1.33 kPa (11.2°C). This behavior was also noted by Pandey (2009). It is believed that the high evaporation temperature is related to a difference in pressure between the system and the center of the potato chip, in which the pressure should be higher than 1.33 kPa in order for water to evaporate at those temperatures. For the remaining time of immersion in oil, the temperature at the center of the chip increased until it reached equilibrium with the frying medium; this period was also longer for the lower frying temperatures.

During the final two steps of the process, pressurization and cooling, the temperature of the chip starts declining down to ambient temperature (~22°C). The rate of cooling during the pressurization period was slower than the one after the chips were out of the fryer, considering that during the pressurization step, the chips are suspended in the warm headspace of the vessel.

4.1.2. Temperature at the surface of the chip (*PC*)

The same thermocouple used to measure temperature at the center of the potato chip was used to measure temperature at the surface by placing it as close as possible to the surface of the chip (Figures 4-1 to 4-3).

The history of the surface temperature was very close to the one for temperature at the center of the chip with some major differences at the beginning of the frying of the immersion frying period. During the depressurization step, the increase of temperature and slight decrease, mentioned in the previous section, was also noted. The most important difference between the center and surface temperature history is that the later does not show the temperature spike followed by the evaporation plateau seen in the center temperature history. The surface temperature rapidly got up to 104ºC in the first 15-20 seconds after immersion in oil, and then continued increasing at a slower rate until it reached the oil temperature. There was no constant temperature related to evaporation since water in the surface evaporates faster than the one in the core of the chip due to direct contact with the frying medium. The depressurization and cooling periods showed the same behavior as the temperature at the center, but with a slightly faster rate of cooling.

4.1.3. Temperature of the vacuum frying vessel headspace (*HS*)

The temperature at the headspace of the vacuum vessel (Figures 4-1 to 4-3) was measured by a thermocouple attached to the lid of the vessel and placed inside the vessel during the complete frying period. This temperature is of great importance in the understanding of the center and surface temperature history behavior.

Before placing the lid on the vessel, the thermocouple reading was ambient temperature; but once the vessel was closed, an immediate increase in temperature (around 60ºC) was observed. This temperature rise was due to the radiant heat from the hot frying oil. Temperature in the vessel headspace remained constant during the depressurization step. Once the chips were submerged into the oil, the headspace temperature increased up to 80, 85, and 88ºC for oil temperature of 120, 130, ad 140ºC, respectively. This second increase in temperature was achieved in 20 seconds after immersion, and is a consequence of the water vapor migrating from the potato chips to the headspace. For the rest of the frying period, this temperature stayed fairly constant (standard deviation within ±2 limit).

After the frying period was over, the basket holding the hot product was raised up to the headspace causing an instant raise in temperature up to 102, 105, 108ºC for the lowest to the highest oil temperature. The headspace maintained this final temperature until the vessel was open and the lid was placed at ambient temperature.

4.1.4. Pressure inside the frying vessel (*P*)

A pressure transducer was attached to the lid and recorded the pressure inside the vessel during the frying process (Figures 4-1 to 4-3). Knowing the pressure history during frying allows a better understanding of the vacuum frying process and is a determining parameter in the study and modeling of oil absorption (Mir-Bel et al, 2009).

The pressure history showed the same behavior and values for the three temperatures studied with a minor difference right after immersion of the potato chips. During the depressurization period, the pressure is lowered from 101.6±0.15 kPa to 1.4±0.06 at a rate of 1.9±0.06 kPa/s. Once the desired pressure is achieved, the potato slices are submerged into the oil causing vapor release and a short increase in pressure of about 7 to 10 kPa; the raise in pressure was more pronounced at the highest frying temperature (140ºC) due to faster water vapor loss to the headspace (Figure 4-3). The vacuum pump rapidly accounted for the increased in pressure and efficiently adjusted the pressure back to the lowest level, from this moment, pressure remained constant until the end of the frying. In the pressurization step, the system recovered ambient pressure at a rate of 1.5±0.17 kPa/s.

4.2. Effect of frying method on temperature history of potato chips during frying

The temperature history for the center (*PC*) and the surface of a potato chip (*PS*), Figure 4-4 and Figure 4-5, respectively, show the results for temperature history of potato slices fried in a vacuum fryer at 120°C and in a traditional fryer at 165°C.

The surface temperature history does not show difference between chips fried under the two methods; however a significant difference was noted in the history for temperature at the center of the chip (Figure 4-4). In traditional frying, the temperature at the center of the chip increased to a value of 107±2ºC once the slices were submerged into the oil; then the evaporation period occurs at 102±1ºC. Even though the center temperature during the first seconds of traditional frying is a slightly higher than the evaporation period, the spike is almost negligible when compared to the temperature spike seen in vacuum frying. This behavior was also observed in a study by Pandey (2009); it was suggested that there is less sudden variations in temperature history during traditional frying because of the negligible pressure difference.

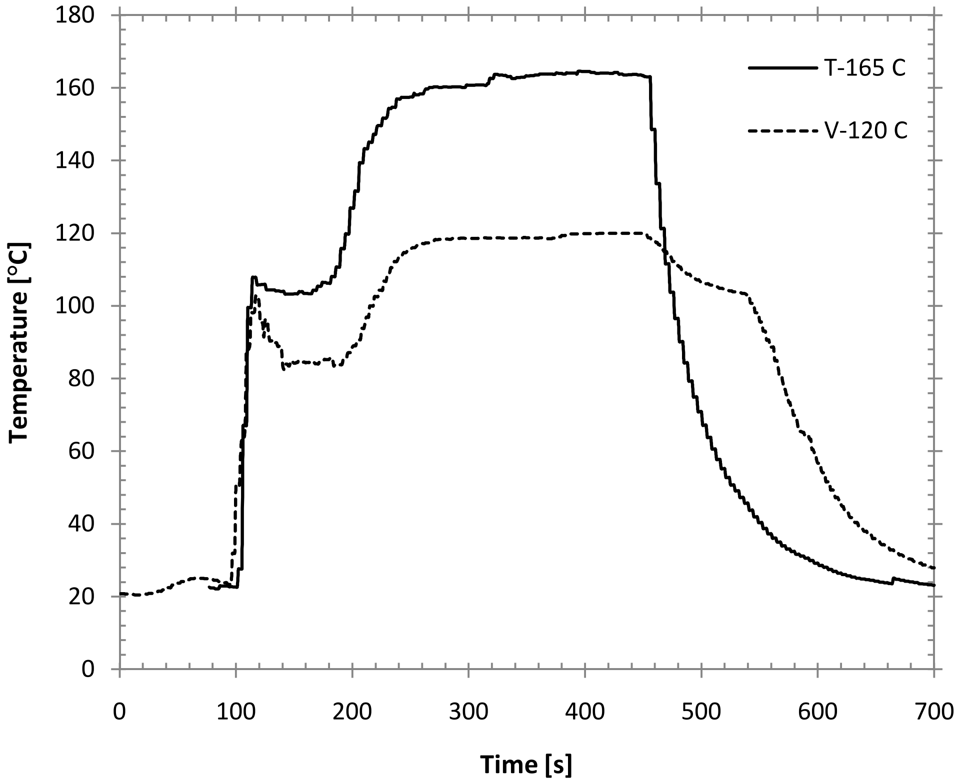


Figure 4-4. Temperature history for temperature at the center of a potato chip (PC) during vacuum frying (V) at 120 ºC and traditional frying (T) at 165 ºC.

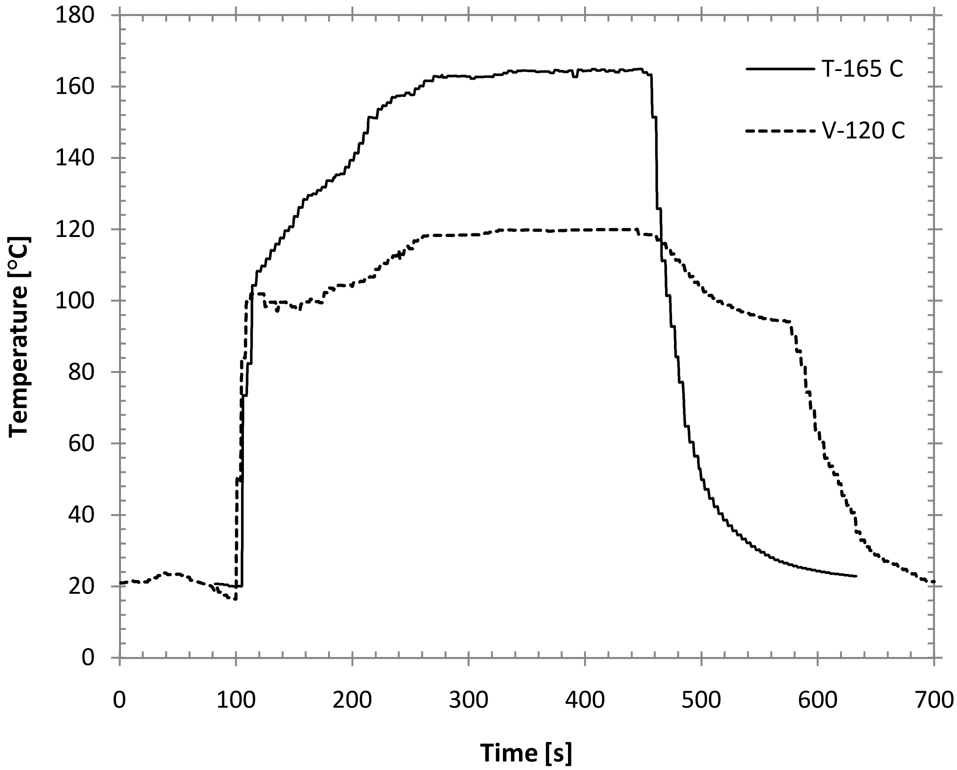


Figure 4-5. Temperature history for temperature at the surface of a potato chip (PS) during vacuum frying (V) at 120 ºC and traditional frying (T) at 165 ºC.

4.3. Effect of oil temperature and frying time on product quality attributes (PQA)

4.3.1. Effect of oil temperature and frying time on moisture loss of potato chips during vacuum frying

Figure 4-6 shows the drying behavior of potato slices fried under vacuum at different oil temperatures (120, 130, and 140°C). Curves of the moisture loss of potato slices fried under vacuum exhibit typical drying behavior for fried food products in accordance with previous findings by Gamble et al. (1987) and Garayo and Moreira (2002). In a typical drying curve, three distinct periods can be observed: (a) the warm-up period in which the wet material absorbs heat from the surrounding media until it reaches the evaporation temperature, (b) the constant rate period where heat is transfer continuously to the material as long as the surface contains water, and (c) the falling rate which continuous until the equilibrium moisture content is reached.

In vacuum frying, the initial warm-up period is very short, it may last one to five seconds (Garayo 2001) since the boiling point of water is lower (11.2°C at 1.33 kPa) and the material reaches the evaporation temperature faster than in other drying processes. Water starts evaporating as soon as the raw material is in contact with the oil. The drying rate is very fast during the first 60-100 seconds of the process, and then slows down as the product reaches equilibrium.

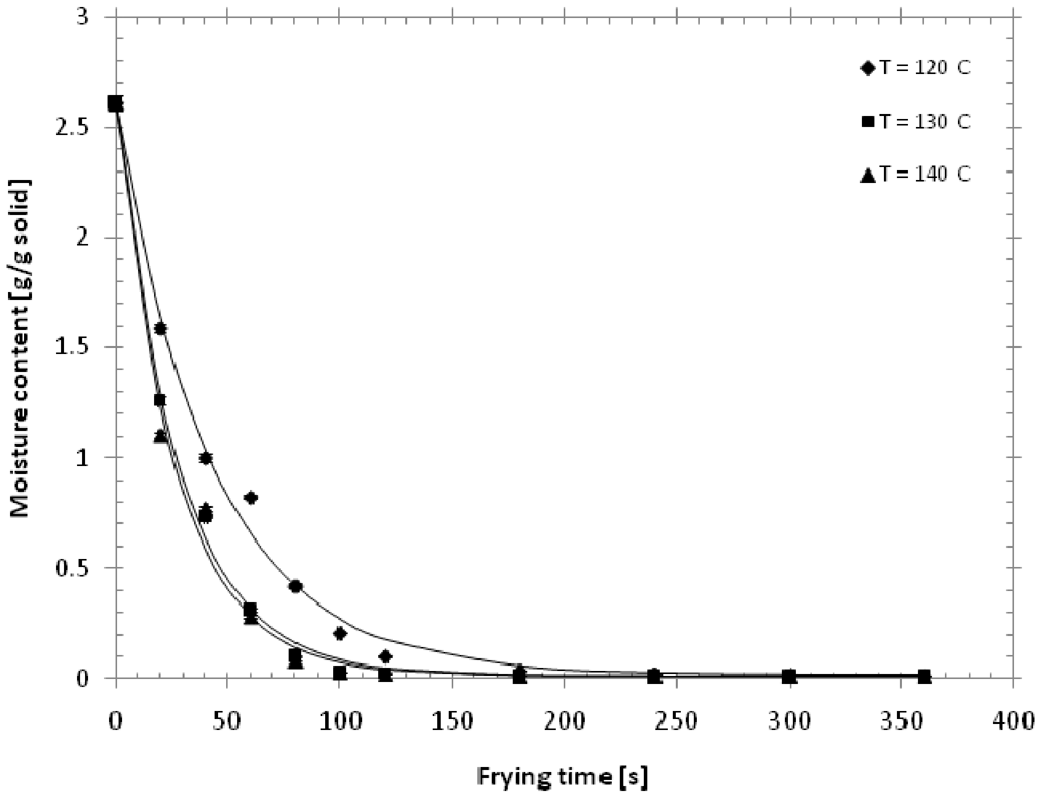


Figure 4-6. Moisture loss of potato chips during vacuum frying at different oil temperatures.

The moisture content of potato slices during vacuum frying vary with oil temperature. The chips fried at 130 and 140°C lost moisture more rapidly than the chips fried at 120°C. For the lower temperature, moisture content reached half of its equilibrium value during the first 45 seconds of frying; while at 130 and 140°C, half of the equilibrium value was obtained 20 and 15 seconds, respectively, after the frying process began. Although differences in moisture content behavior were observed among frying temperatures; there was no significant difference ($P < 0.05$) in the final moisture content (0.015±0.0007 g/g solid) between different temperatures.

The drying rate during frying is controlled by moisture diffusion mechanisms; higher moisture diffusion coefficient, a measure of molecular mobility, means faster drying rate (Datta, 2002). The diffusion coefficient of potato slices during vacuum frying at different temperatures was calculated using a method similar to the one proposed by Broker et al. (1992) for a flat plate. The moisture diffusion coefficient, D_e, was calculated by:

$$MC_{db} = (M_o - M_e)\exp\left(\frac{\pi^2 D_e t}{4a^2}\right) + M_e \qquad [4\text{-}1]$$

where MC_{db} is the moisture content in (g/g solid), M_o is the initial moisture content (g/g solid), M_e is the equilibrium moisture content (g/g solid), t is the frying time (s), and a is half of the thickness of the potato slice (m).

The values of the moisture diffusion coefficient were obtained by using non-linear regression to fit the experimental moisture content data. The results from these calculations are shown in Table 4-1.

In agreement with results by Moreira et al. (2009), the moisture diffusion coefficient for potato chips during vacuum frying is higher at higher frying temperatures. This is due to the fact that there is more heat transfer at higher temperatures, and hence faster evaporation of water in the product.

Table 4-1. Diffusion coefficients for potato chips fried under vacuum at different oil temperatures.

Temperature	M_o **[g/g solid]**	D_e **[m^2/s]**	M_e **[g/g solid]**	R^2
120	2.6114	5.9658×10^{-7}	0.0154	0.998
130	2.6114	8.3378×10^{-7}	0.0150	0.994
140	2.6114	9.8565×10^{-7}	0.0146	0.994

The influence of the frying oil temperature on the moisture diffusion coefficient during vacuum frying was modeled using an Arrhenius type equation:

$$D_e(T) = A \cdot \exp\left(\frac{-E_a}{RT}\right) \quad [4\text{-}2]$$

where A is the pre-exponential factor, E_a is the activation energy, T is the absolute temperature in Kelvin, and R is the universal gas constant (8.314 J/mol K).

Equation (4-2) can be linearized as:

$$\ln D_e = \ln A - \frac{E_a}{RT} \quad [4\text{-}3]$$

The following relationship was found (Figure 4-7):

$$\ln D_e = -3.9085 - 4088.1\frac{1}{T} \quad [4\text{-}4]$$

The pre-exponential factor (A) for moisture diffusion coefficient of potato chips fried under vacuum was 2.0×10^{-2} s^{-1}, and the activation energy (E_a) was 33,988 J/mol for the temperature range from 120 to 140°C.

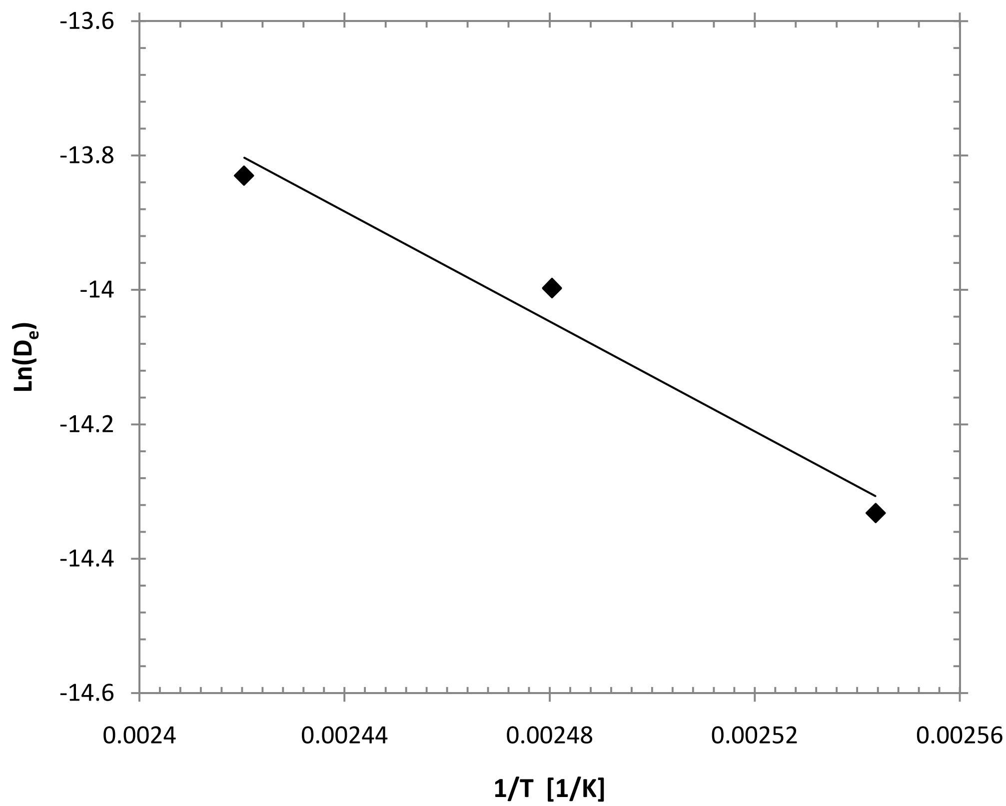


Figure 4-7. Effect of frying temperature on the moisture diffusion coefficient (D_e) of potato chips fried under vacuum.

4.3.2. Effect of oil temperature and frying time on oil content and distribution during vacuum frying of potato chips

4.3.2.1. Internal oil content during vacuum frying of potato chips

The internal oil content of the potato chips, the final oil content of the product after the de-oiling step, was determined at three different temperatures under vacuum frying (Figure 4-8). The internal oil content (IOC) of the vacuum fried potato chips was 0.072±0.004, 0.062±0.003, and 0.059±0.003 g/g solid for frying temperatures of 120, 130, and 140°C, respectively. These values are significantly lower than those found in traditionally fried potato chips which have an average oil content of 33%, wet basis (0.50 g/g solid).

The IOC accounted only for 13-17% of the total oil content (TOC) for all three temperatures and 83-87% of the TOC was surface oil content (SOC) which was easily removed by the de-oiling system. IOC was found to be inversely proportional to the frying temperature; this phenomenon can be the result of reduced oil viscosity at higher temperatures which makes the removal of oil easier during the de-oiling (centrifuging) process. Potato chips fried at 120°C had an IOC significantly different ($P<0.05$) from those of the chips fried at 130°C and 140°C, however, the latter ones did not show significant different between them. The oil distribution for potato chips fried under vacuum for the three temperatures studied are represented in the figures on pages 63-65.

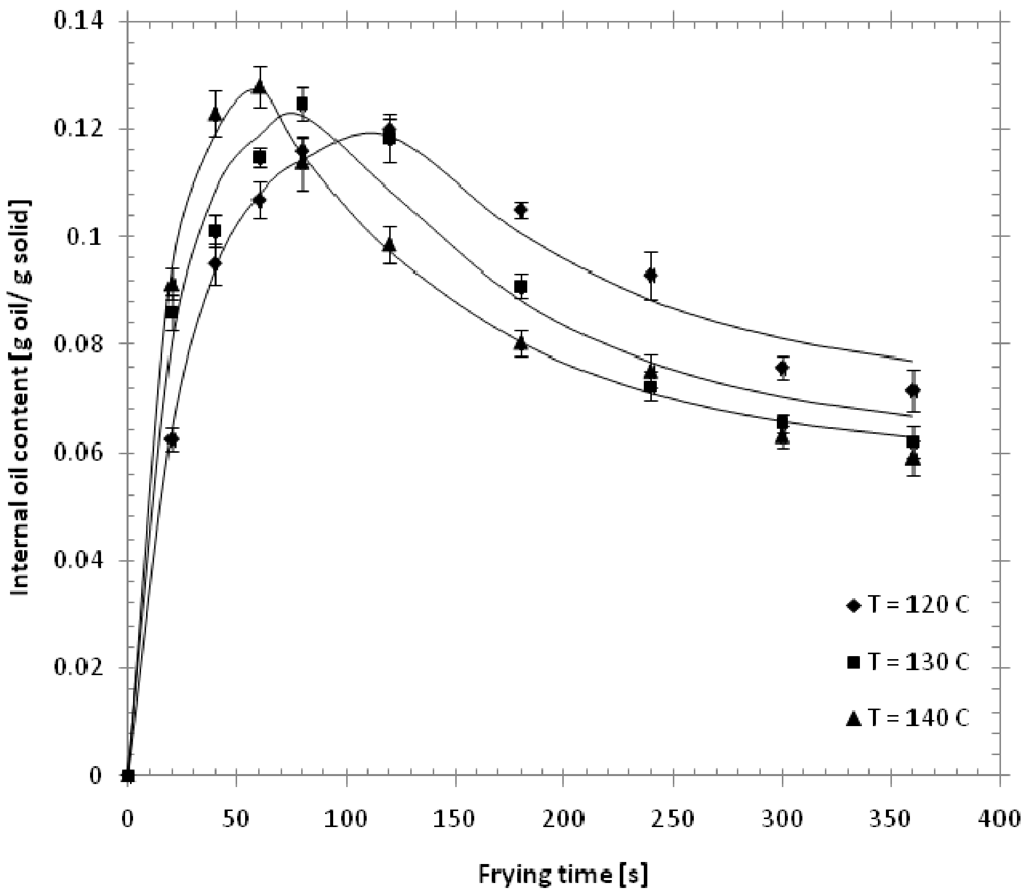


Figure 4-8. Effect of temperature and frying time on internal oil content (IOC) of potato chips fried under vacuum.

The internal oil content was modeled using the fractional conversion kinetic model (Chen and Ramaswamy, 2002):

$$OR = \frac{OC(t) - OC_e}{OC_o - OC_e} = A \cdot \exp(-kt) \qquad [4\text{-}5]$$

where OR is the oil ratio, OC_e is the equilibrium oil content, OC_o is the initial oil content, A and k are the regression coefficients, and t is frying time. Table 4-2 shows the values of the kinetic parameters used in Equation (4-5).

This equation can be rearranged to obtain a model for oil content as a function of time:

$$OC(t) = A \cdot \exp(-kt)(OC_o - OC_e) + OC_e \qquad [4\text{-}6]$$

For each temperature, two regions were defined for the kinetic model considering that each curve presents different behaviors before and after the maximum oil content reached during frying. At higher temperatures, the maximum oil content was higher and reached earlier in the frying process, and then decreased as frying time increased. The peak values for internal oil content during frying were 0.112±0.003, 0.124±0.003, and 0.128±0.004 g/g solid, from the lowest to the highest temperature.

Table 4-2. Regression coefficients of the fractional conversion kinetic model for internal oil content (IOC) in potato chips during vacuum frying at different oil temperatures.

Temperature [°C]	**Time range [s]**	OC_o [a]	OC_e [b]	*A* **[g/g solid]**	***k*** **[1/s]**	R^2
120	0-120	0.001	0.114	1.003	0.038	0.999
	120-360	0.114	0.077	3.171	0.009	0.935
130	0-80	0.001	0.122	0.990	0.050	0.988
	80-360	0.122	0.067	2.356	0.010	0.946
140	0-60	0.001	0.119	1.003	0.067	0.997
	60-360	0.119	0.067	1.767	0.010	0.989

[a] Initial oil content [g/g solid]
[b] Equilibrium oil content [g/g solid]

4.3.2.2. Total and surface oil content during vacuum frying of potato chips

The final total oil contents of the potato chips fried under vacuum were 0.410±0.005, 0.475±0.004, and 0.457±0.007 g/g solid for frying temperatures of 120, 130, and 140°C, respectively; thus, the higher the oil temperature, the higher the total oil uptake by the potato chips. The final values of oil content are comparable with those obtained in traditional frying since oil is drastically absorbed during the pressurization stage of the process where the pressure difference ($P_{surroundings} - P_{pore}$) drives the surface oil into the product.

Oil absorption occurs very rapidly since almost 75% of the total oil content is absorbed between the first 70 and 80 seconds of frying. After that time interval, the TOC remained fairly constant until the frying process was finished. Similar findings were also reported by Shyu and Hwang (2001), Garayo and Moreira (2002), and Granda (2005). The curves for total oil content during vacuum frying at different temperatures (Figure 4-9) show the same shape and behavior, the only difference is that the equilibrium value is reached faster at higher temperatures. This indicates that the final oil content of the chips is a function of time and the remaining moisture within the product, which increases with decreasing temperature (Garayo and Moreira, 2002).

The effect of the pressurization step can be diminished by the use of the de-oiling system. Surface oil content was defined as the difference between TOC and IOC, and it is the oil removed by the de-oiling system before the pressurization step. The final values of SOC were 0.339±0.006, 0.413±0.006, and 0.398±0.010 g/g solid, from the lowest to the highest temperature. This type of oil followed the same behavior as that of the TOC in which it the maximum value is reached fast and then it remains constant for the rest of the process. The effect of temperature and frying time on SOC is shown is Figure 4-10. By evaluating the difference between the total oil content and the internal oil content, the importance of the de-oiling system in vacuum frying processes, discussed by Moreira et al. (2009), is confirmed. The efficacy of the de-oiling system on reducing the final oil content of potato chips fried under vacuum is shown in the oil distribution graphs (Figure 4-11, Figure 4-12, and Figure 4-13)

The kinetics of oil distribution, TOC and SOC, on potato chips was modeled using a special case of the logistic kinetic model (Chen and Ramaswamy, 2002) that accurately describes product quality attributes that increase exponentially and eventually level off:

$$OC(t) = A_o + \frac{A}{1+\exp\left[-k(t-t_o)\right]} \qquad [4\text{-}6]$$

where O*C* is the quality variable, oil content, at time t (s), A_o is the quality attribute before frying, A is a constant value related to the equilibrium quality attribute, k is the rate constant (1/s), and t_o (s) is the time constant value when the quality attribute is half A value. Table 4-3 shows the values of the parameters in Equation (4-6) for different frying temperatures.

Table 4-3. Regression coefficients of the time dependent model for total oil (TOC) and surface oil (SOC) content in potato chips during vacuum frying at different oil temperatures.

Temperature [°C]		***A* [g/g solid]**	**t_o [s]**	***k* [1/s]**	**R^2**
120	TOC	0.398	48.671	0.049	0.975
	SOC	0.321	73.706	0.033	0.949
130	TOC	0.485	53.813	0.044	0.985
	SOC	0.410	73.540	0.044	0.995
140	TOC	0.477	50.791	0.046	0.975
	SOC	0.405	70.002	0.054	0.990

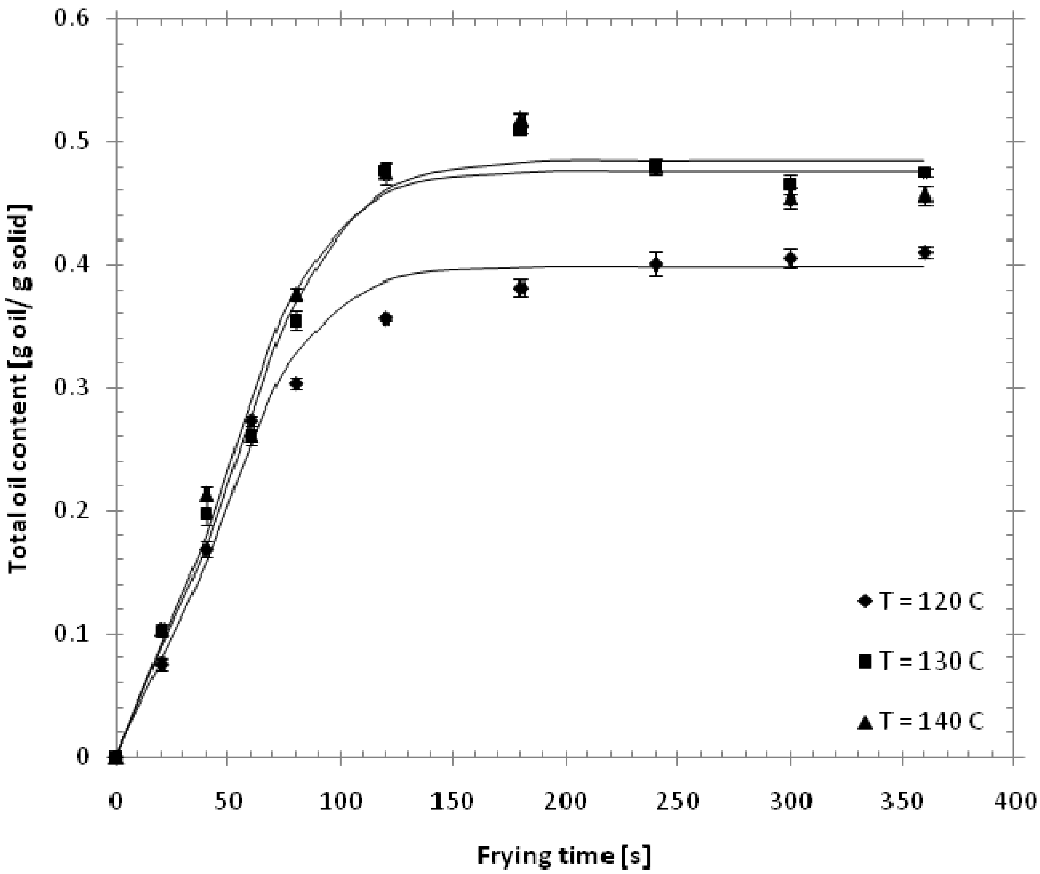


Figure 4-9. Effect of temperature and frying time on total oil content (TOC) of potato chips fried under vacuum.

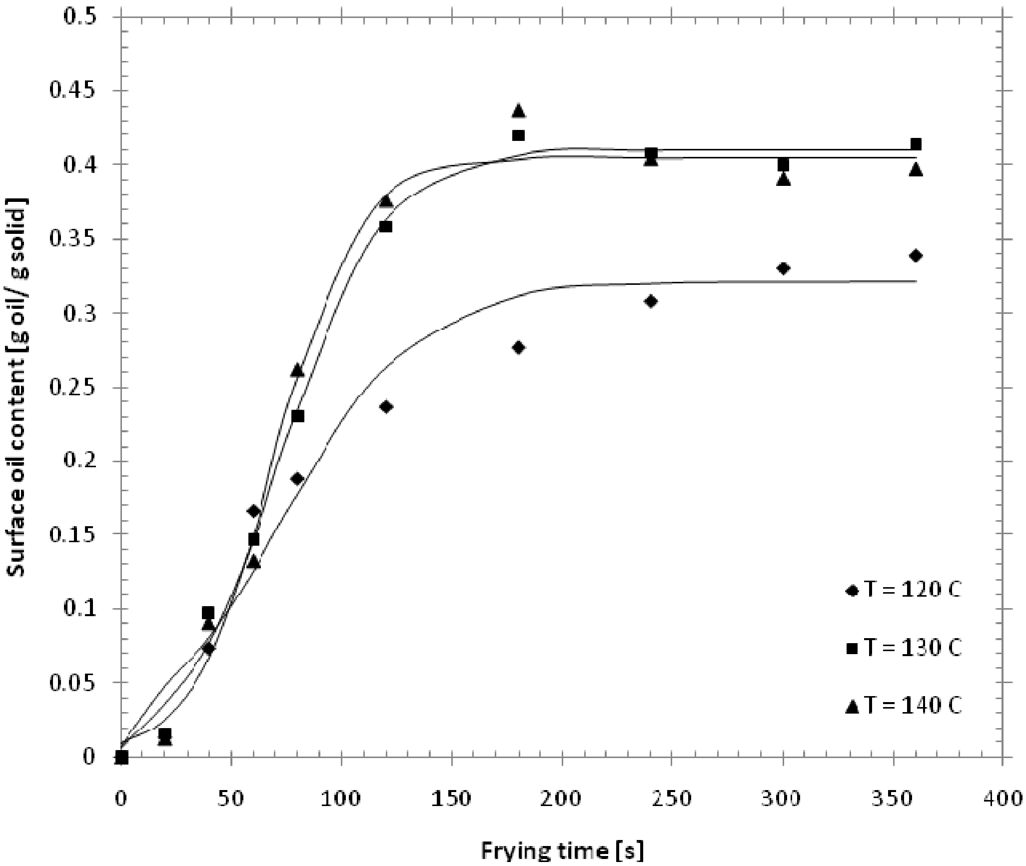


Figure 4-10. Effect of temperature and frying time on surface oil content (SOC) of potato chips fried under vacuum.

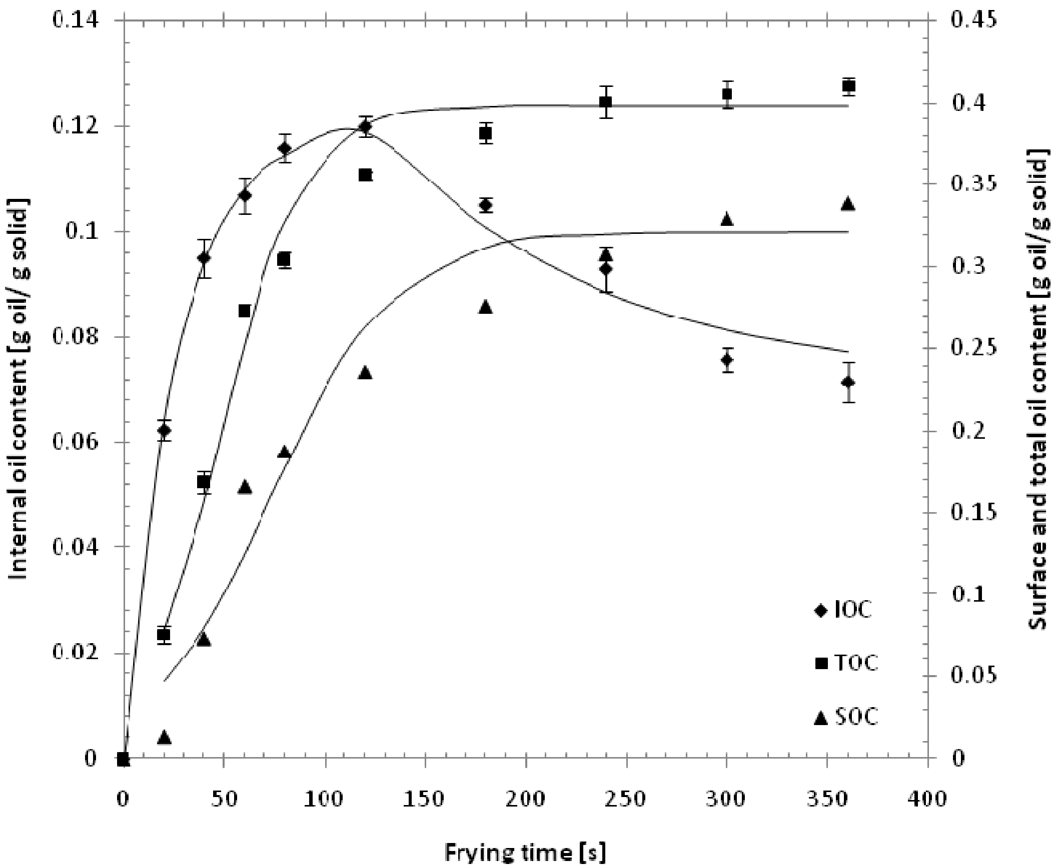


Figure 4-11. Oil distribution of potato chips fried under vacuum at 120°C.

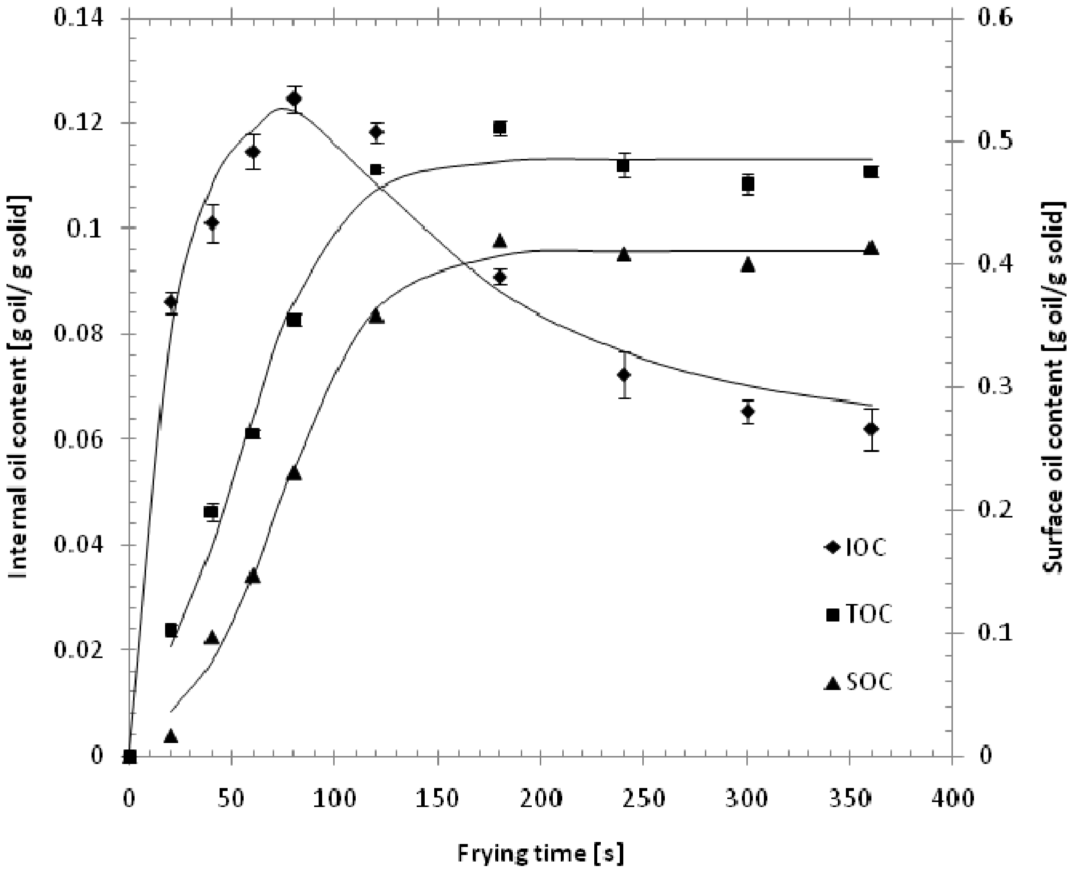


Figure 4-12. Oil distribution of potato chips fried under vacuum at 130°C.

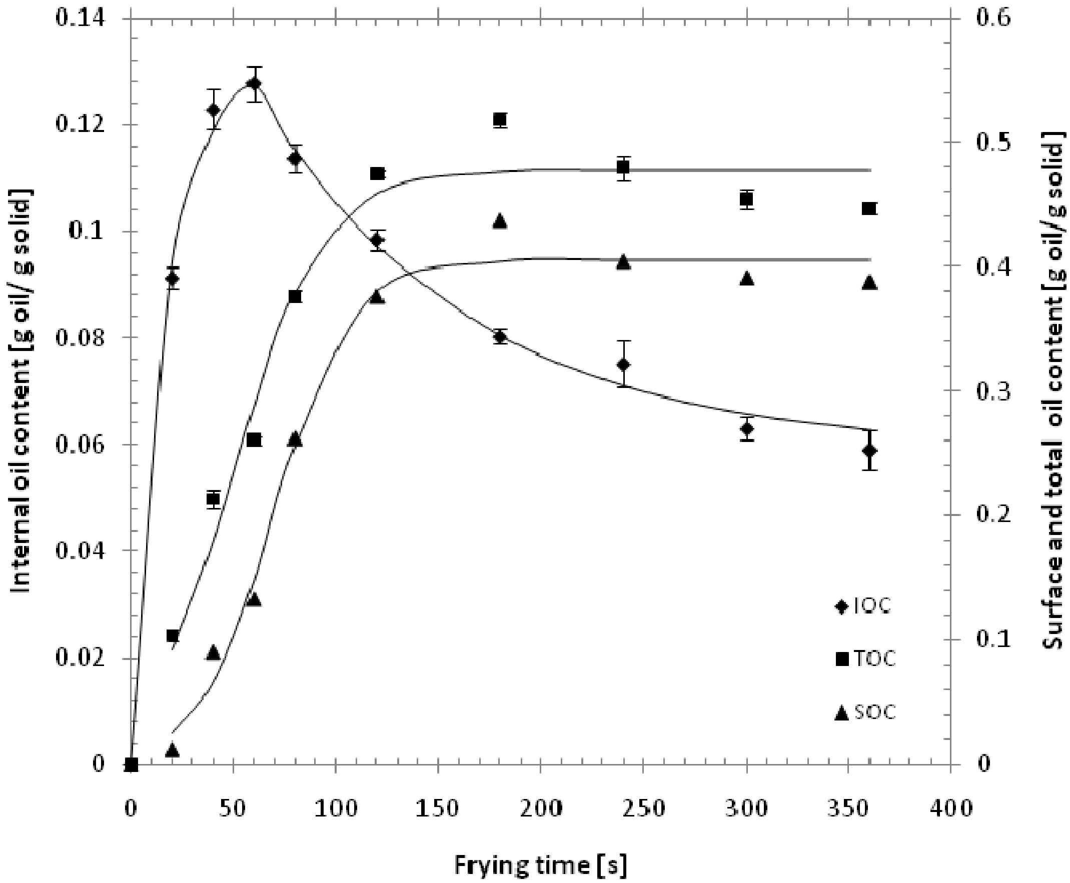


Figure 4-13. Oil distribution of potato chips fried under vacuum at 140°C.

4.3.3. Effect of oil temperature and frying time on porosity of potato chips during vacuum frying

The kinetics of bulk and true density of vacuum-fried potato chips was evaluated at frying temperatures of 120, 130, and 140ºC. In this study, bulk and true density were calculated for the samples containing water, but no oil. This method allows a better understanding of the actual available space that can be occupied by fluids during frying.

Porosity values depend on bulk density and true density values; Table 4-4 depicts the final values of these properties for potato chips fried under vacuum at different temperatures. The final values of the mentioned properties were not significantly different ($P<0.05$) between frying temperatures; however different rates of change were observed throughout the frying period.

During frying, bulk density decreases from an initial average value of 1103±3 kg/m^3 to 453±4 kg/m^3, while true density increased from 1088 kg/m^3 to 1404±4 kg/m^3. These changes in both densities cause an increase in porosity during frying. This behavior has been previously reported during frying of sweet potato, potato, and mango chips by Taiwo & Baik (2007), Moreira et al. (2009) and Nunes and Moreira (2009).

The effect of temperature on the rate of change in true and bulk density, as well as, porosity is shown in Figure 4-14, Figure 4-15, and Figure 4-16, respectively. It can be seen that the final value of porosity (0.681±0.004) is reached faster at higher temperatures (Figure 4-16), as a consequence of the same behavior occurring in bulk and true density which is attributed to moisture loss in the sample.

The experimental data for true density and porosity were modeled using Equation 4-6 by changing the quality attribute for the desired variable; Table 4-5 and Table 4-6 show the values of the regression coefficient for the models. A slight modification was made to Equation 4-6 to model bulk density considering that this variable decreases with time.

$$\rho_b(t) = A_o - \frac{A}{1+\exp\left[-k(t-t_o)\right]} \qquad [4\text{-}7]$$

The parameters for this model are summarized in Table 4-7.

Table 4-4. Final true density, solid density, and porosity of potato chips fried under vacuum at different oil temperatures.

Temperature [°C]	**True density [kg/m^3]**	**Bulk density [kg/m^3]**	**Porosity**
120	1408±2	452±2	0.686±0.006
130	1400±2	458±1	0.678±0.07
140	1404±5	451±4	0.679±0.10

Table 4-5. Regression coefficients for the time dependent model for porosity in potato chips during vacuum frying at different oil temperatures.

Temperature [°C]	***A* [-]**	**t_o [s]**	***k* [1/s]**	**R^2**
120	0.677	76.291	0.050	0.991
130	0.690	54.075	0.069	0.991
140	0.684	43.112	0.080	0.996

Table 4-6. Regression coefficients for the time dependent model for true density in potato chips during vacuum frying at different oil temperatures.

Temperature [°C]	***A* [kg/m^3]**	**t_o [s]**	***k* [1/s]**	**R^2**
120	312	76.042	0.038	0.994
130	315	50.387	0.055	0.996
140	316	48.777	0.058	0.991

Table 4-7. Regression coefficients for the time dependent model for bulk density in potato chips during vacuum frying at different oil temperatures.

Temperature [°C]	***A* [kg/m^3]**	**t_o [s]**	***k* [1/s]**	**R^2**
120	652	82.795	0.050	0.985
130	655	58.628	0.077	0.987
140	649	49.545	0.058	0.999

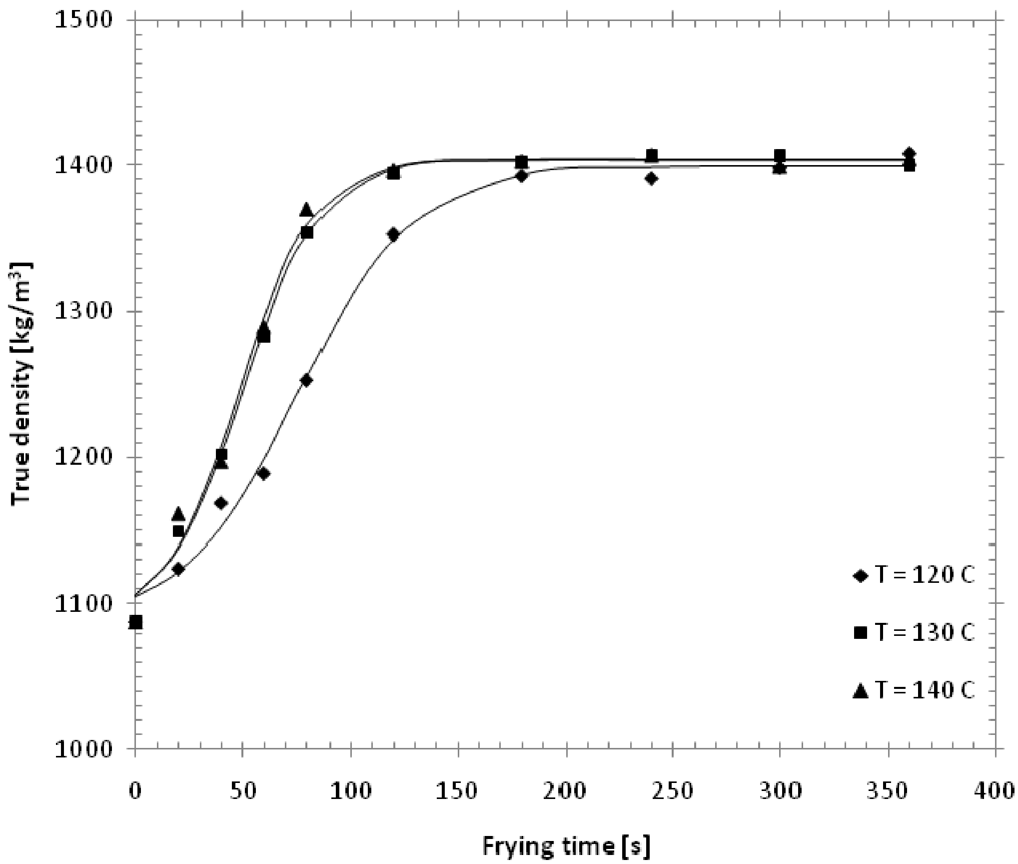


Figure 4-14. Effect of temperature and frying time on true density of potato chips fried under vacuum.

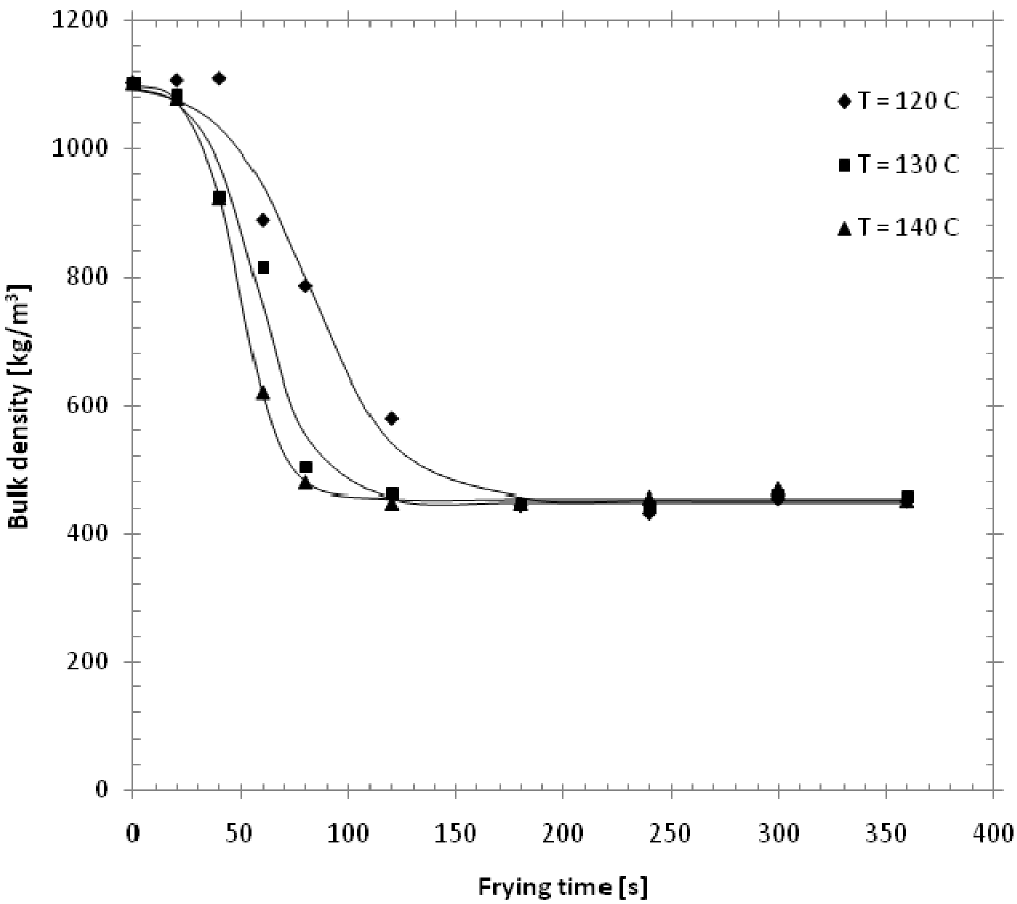


Figure 4-15. Effect of temperature and frying time on bulk density of potato chips fried under vacuum.

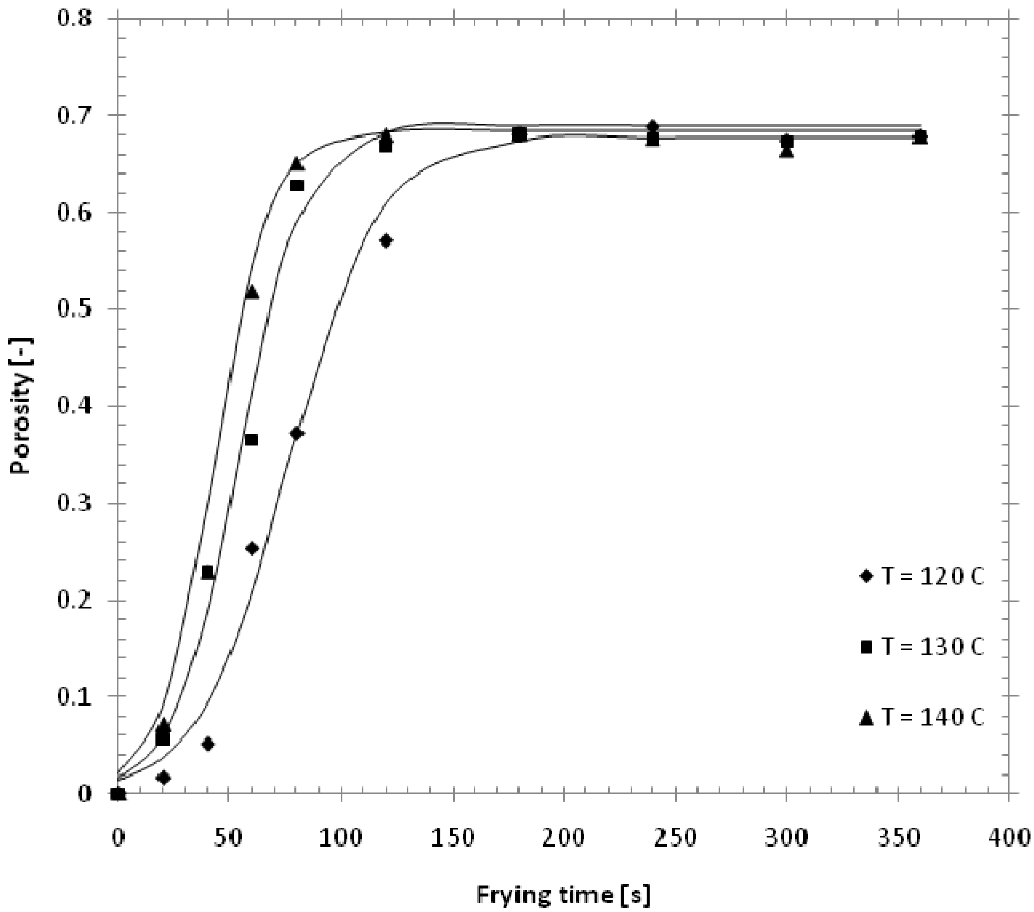


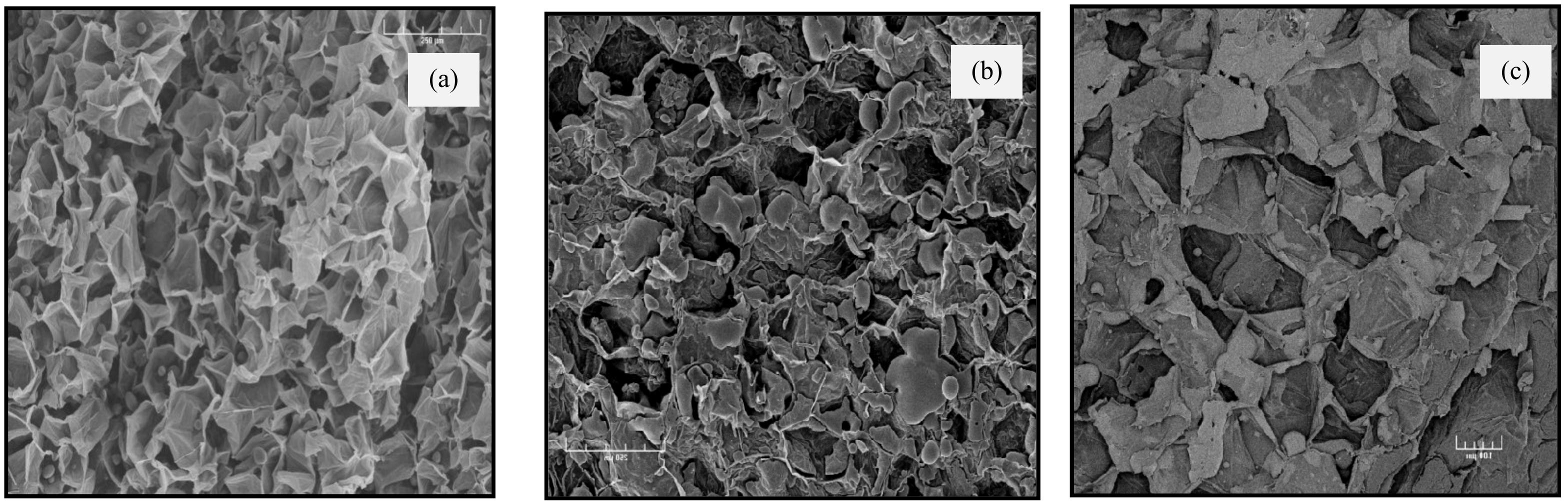
Figure 4-16. Effect of temperature and frying time on porosity of potato chips fried under vacuum.

4.3.4. Effect of frying time and frying method on microstructure of potato chips during vacuum frying

The microstructure of raw potato slices and potato chips, fried in vacuum (120ºC) and traditional frying (165ºC), was studied by means of Scanning Electron Microscopy (SEM). Images were taken at different magnifications (x100, x500, x1000) in order to visualize more details on each sample. There were two images taken at x100 magnification, one of the surface of the sample and one of a cross-sectional cut made by a natural fracture. All other images were taken from the cross-sectional cut since it provided more information about the actual structure of the sample. The SEM images are shown from Figure 4-17 through Figure 4-23.

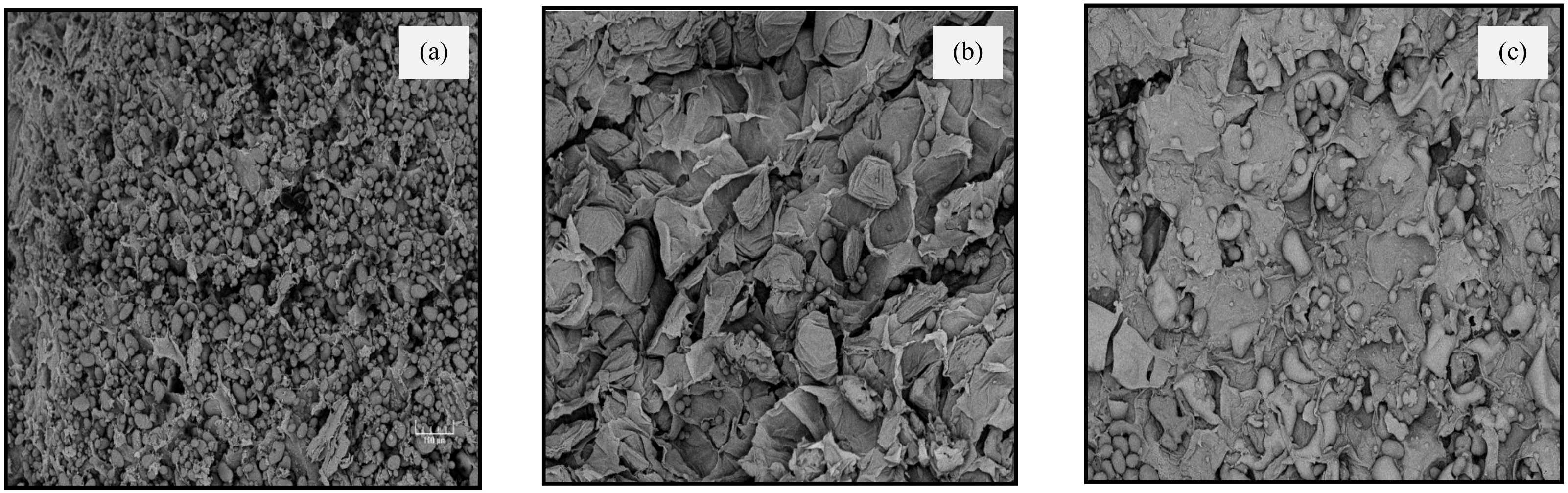
Figure 4-17(a) shows the fresh potato cells; the intact cells of fresh potato tissue are almost in perfect contact with each other. This image gives a good starting point for comparison since the polyhedral shape of the cell walls is seen very clear; however the surface of the slice has been damaged by the cut made by a blade for processing and the components of the cells have been washed away. A better look at the actual structure and the contents of the plant cells can be seen in the cross-section image of the raw potato showed (Figure 4-18(a)) where numerous starch granules of size ranging from 120-400 μm in length were observed.

At 60 seconds of frying (Figure 4-18 (b)), the cells look compacted as water escapes from the tissue. Also, there are less starch granules and they are dispersed between the creases of the structure. After water has evaporated, at 180 seconds of frying (Figure 4-18 (c)), some of the cells walls collapsed and the components of the



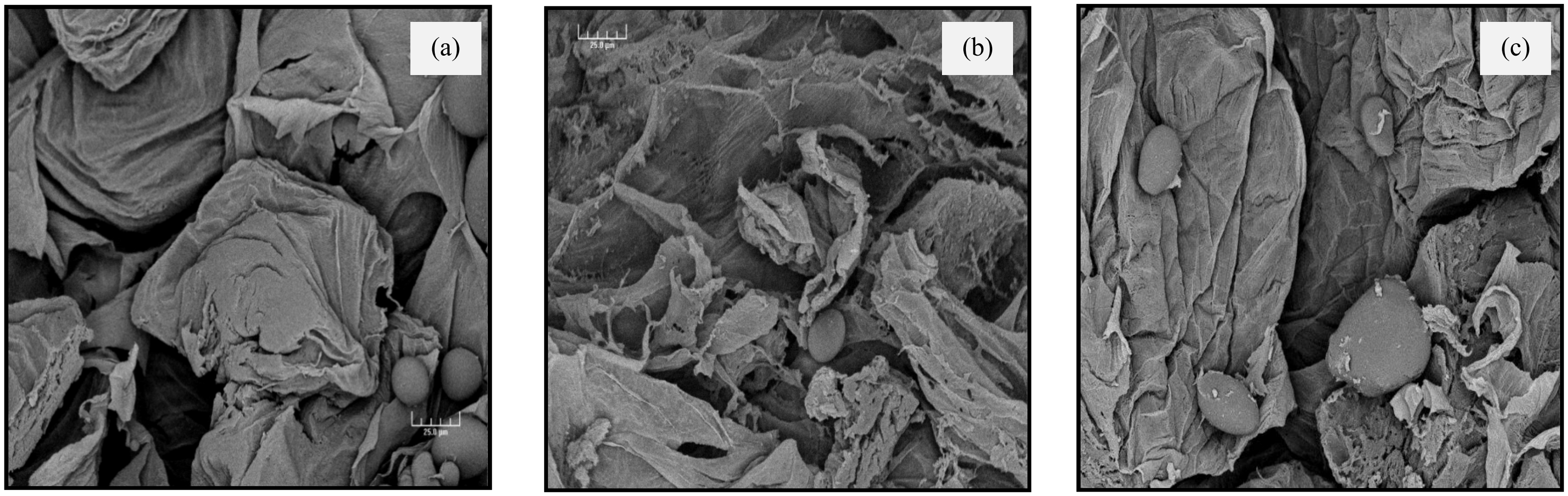
Scale:1 in = 400 μm 15 kV x100

Figure 4-17. SEM image of the surface of a raw potato slice (a) and potato chips fried under vacuum (1.33 kPa) at 120 ºC for 60 s (b), and 180 s (c) (x100).



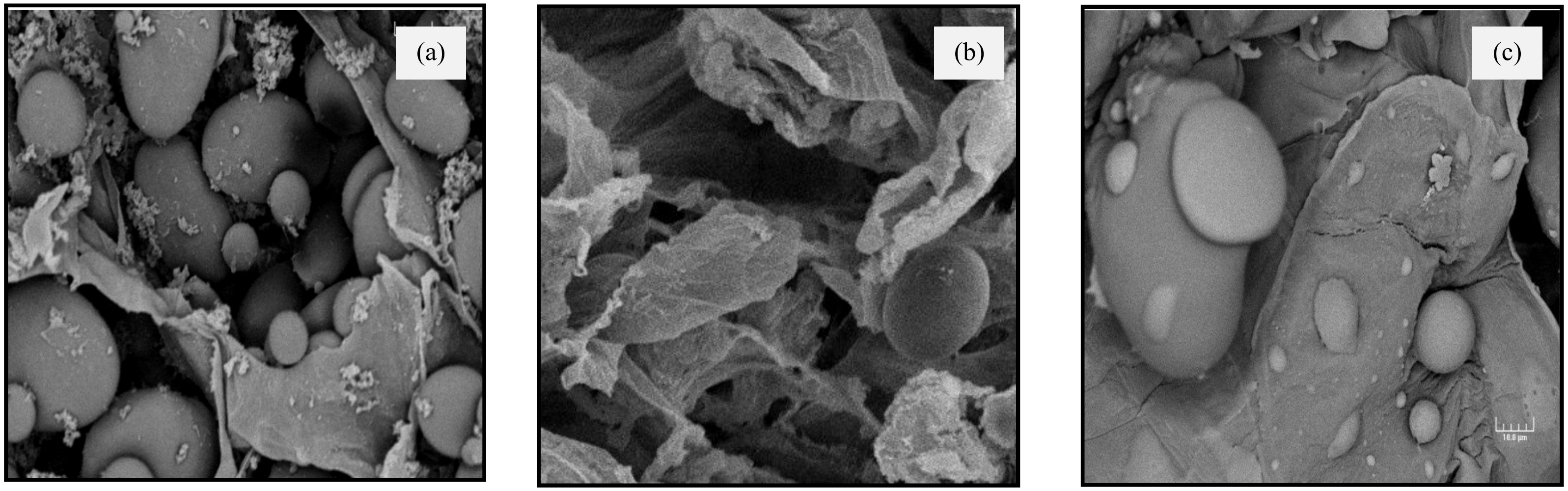
Scale:1 in = 400 μm 15 kV x100

Figure 4-18. SEM image of the cross-section of a raw potato slice (a) and potato chips fried under vacuum (1.33 kPa) at 120 ºC for 60 s (b), and 180 s (c) (x100).



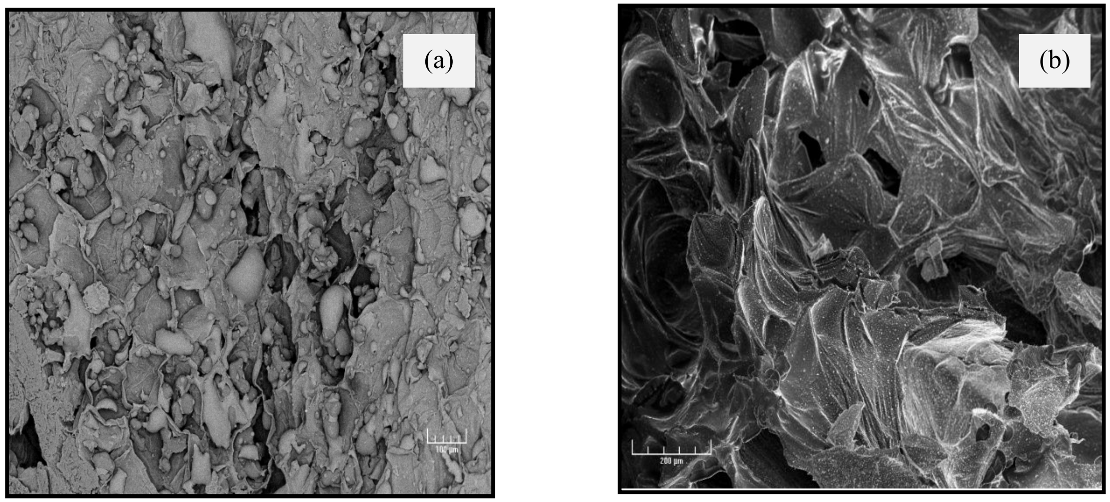
Scale:1 in = 100 μm   15 kV   x500

Figure 4-19. SEM image of the cross-section of a raw potato slice (a) and potato chips fried under vacuum (1.33 kPa) at 120 ºC for 60 s (b), and 180 s (c) (x500).



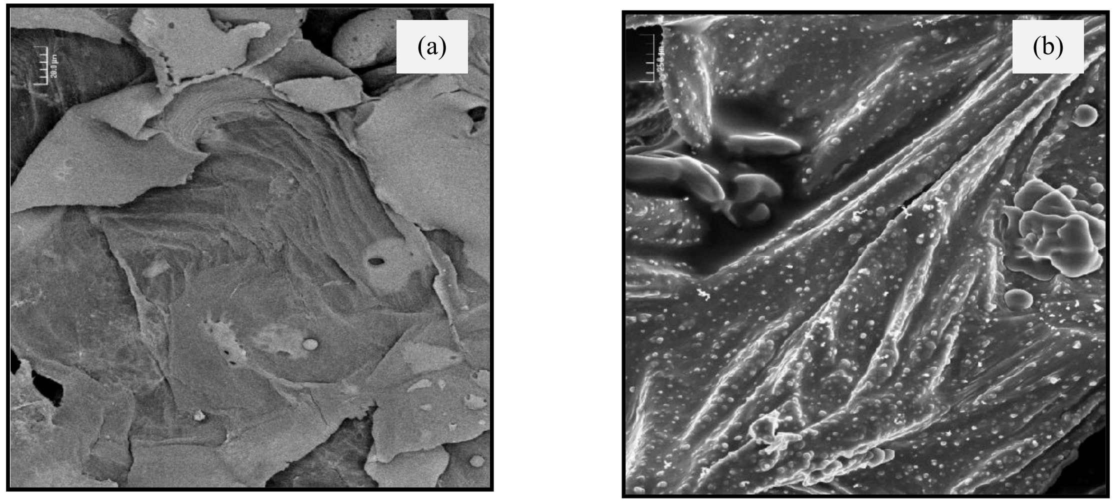
Scale:1 in = 50 µm 15 kV x1000

Figure 4-20. SEM image of the cross-section of a raw potato slice (a) and potato chips fried under vacuum (1.33 kPa) at 120 ºC for 60 s (b), and 180 s (c) (x1000).



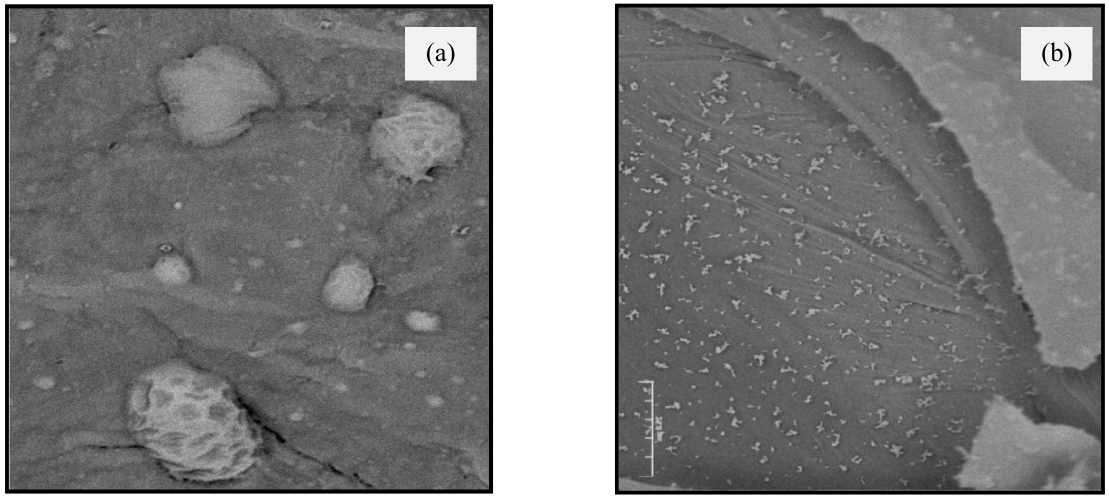
Scale:1 in = 400 μm   15 kV   x100

Figure 4-21. SEM image of the cross-section of potato chips fried under vacuum (1.33 kPa) at 120 ºC for 360 s (a), and at atmospheric pressure at 165 ºC for 360 s (b) (x100).



Scale:1 in = 100 µm 15 kV x500

Figure 4-22. SEM image of the cross-section of potato chips fried under vacuum (1.33 kPa) at 120 ºC for 360 s (a), and at atmospheric pressure at 165 ºC for 360 s (b) (x500).



Scale:1 in = 50 μm   15 kV   x1000

Figure 4-23. SEM image of the cross-section of potato chips fried under vacuum (1.33 kPa) at 120 ºC for 360 s (a), and at atmospheric pressure at 165 ºC for 360 s (b) (x1000).

plant cell start lost their individual characteristics and form a whole mass filling the whole interior of the cell; only a few granules still retain somewhat their characteristic shape.

At the x500 magnification image (Figure 4-19), the changes in structure of the samples can be better visualized. The cell structure is broken and some intact starch granules are still present even after 180 seconds of frying. A higher magnification (x1000) shows much fewer starch granules after 180 seconds of frying (Figure 4-20).

Figure 4-21 shows the structure of the vacuum-fried chip at 120^{o}C for 360 seconds compared to the traditionally-fried chips at 165^{o}C for 380 seconds. In the chip fried at atmospheric pressure, the cell structure can barely be recognized and there is no trace of starch granules with preserved shape.

At higher magnification (x500), the changes in granule shape can be observed (Figure 4-22). The image of the vacuum-fried chip for 360 seconds with a x1000 magnification (Figure 4-23(a)) shows a starch granule with a singular surface. This type of change is surface was also reported by Blaszczak et al. (2004) for potato starch granules at high pressure. At this same magnification, the traditionally-fried chip shows a completely different structure (Figure 4-23(b)) since it only shows the wrinkled surface of the collapse cell with some trace of material that probably erupted from starch granules. The brightness of this image is evidence of oil presence in the sample.

The results obtained in this study are supported by several researchers who have explained that when starch is heated in water (as in frying), the granules go through the gelatinization process, which includes hydration, swelling, and rupture of the structure

(Liu and Shi, 2006). Moreover, Aguilera et al. (2001) reported that, during frying, cells shrink and their walls become wrinkled and convoluted around dehydrated gelled starch but are not ruptured During frying, the cells of the potato become dehydrated as water is released from the intercellular spaces in the form of steam. It has been postulated that cells shrink and their walls become wrinkled and convoluted around dehydrated gelled starch but are not ruptured.

In summary, microstructure during frying is constantly changing since it is affected by the heat transfer and moisture loss. Cells retain their shape while the inside material changes during the heat and mass processes that occur during frying. Also, there are changes on the surface of the cell related to shrinkage.

4.3.5. Effect of oil temperature and frying time on diameter shrinkage and thickness expansion of potato chips during vacuum frying

Diameter shrinkage and thickness expansion at during vacuum frying at different temperatures were determined using Equation 3-8 and Equation 3-9 and the results are presented in Figure 4-24 and Figure 4-25, respectively.

Frying temperature was found not to be a determining factor ($P<0.05$) in the final values of diameter and thickness changes; nonetheless, the rate of change of both variables was a function of frying temperature. Diameter shrinkage was higher at 140°C than at the lower temperatures; this is due to the fact that higher temperature causes the sample surface to become rigid faster, thus producing increased resistance to volume change. The change in diameter showed several fluctuations at lower temperatures compared with the highest temperature, where the final diameter is reached faster. An interesting characteristic of the diameter shrinkage curves, for all temperatures, is the presence of a sudden decrease in change (highest diameter value) followed by an immediate increase. The minimum values in diameter shrinkage were 7.02±0.49% (at 120 s), 8.54±0.52% (at 40 s), and 5.41±0.59% (at 20 s) for 120, 130 and 140ºC, respectively. Then the chips continued shrinking, at a slower rate until equilibrium was reached. The final values for diameter shrinkage were 8.93±0.40%, 9.52±0.39%, and 8.45±0.33% for the lowest to the highest temperature, respectively. It was noted, by visual observation, that the chips initially shrank at a fast rate due to rapid water loss and then expanded during crust formation (lowest change value).

The relation between diameter shrinkage and moisture loss during frying was previously reported by (Moreira et al. (1999), Caixeta et al., (2002), and Tran et al. (2007). Also, Moreira et al. (2008) observed a similar shrinkage behavior for vacuum fried potato chips at 120 and 130^{o}C; and Kawas (2000) found a sudden decrease in the diameter of freeze-dried and steamed-baked tortilla chips after the first 8 seconds of traditional frying at 190^{o}C.

Thickness of the chips was rapidly reduced (negative values) down to 36% during the first 20 seconds of frying and then it started increasing slowly up to the value of 3.4±0.3% thickness expansion. The main effect of frying temperature on thickness variation was the time at which equilibrium was reached; as in diameter shrinkage, equilibrium was reached faster at high temperatures. Thickness changes were fitted to a polynomial equation for each temperature (See Figure 4-25).

Garayo (2001) analyzed the small changes in thickness observed in vacuum-fried potato chips vacuum fried chips, and explained that once the fryer has been evacuated, the water vapor expands with little resistance even before frying starts and during frying, little expansion may be produced by the superheated vapor trying to escape the pore space.

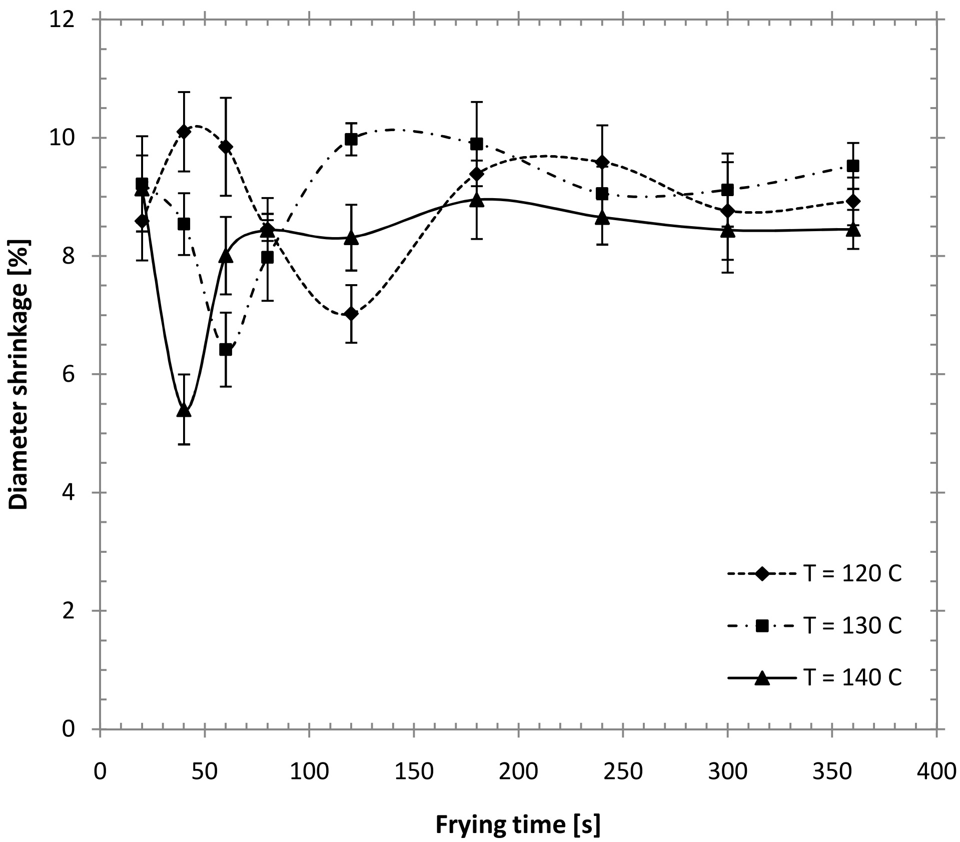


Figure 4-24. Effect of oil temperature on potato chips diameter shrinkage during vacuum frying. Connecting lines were used to allow a better understanding of experimental data.

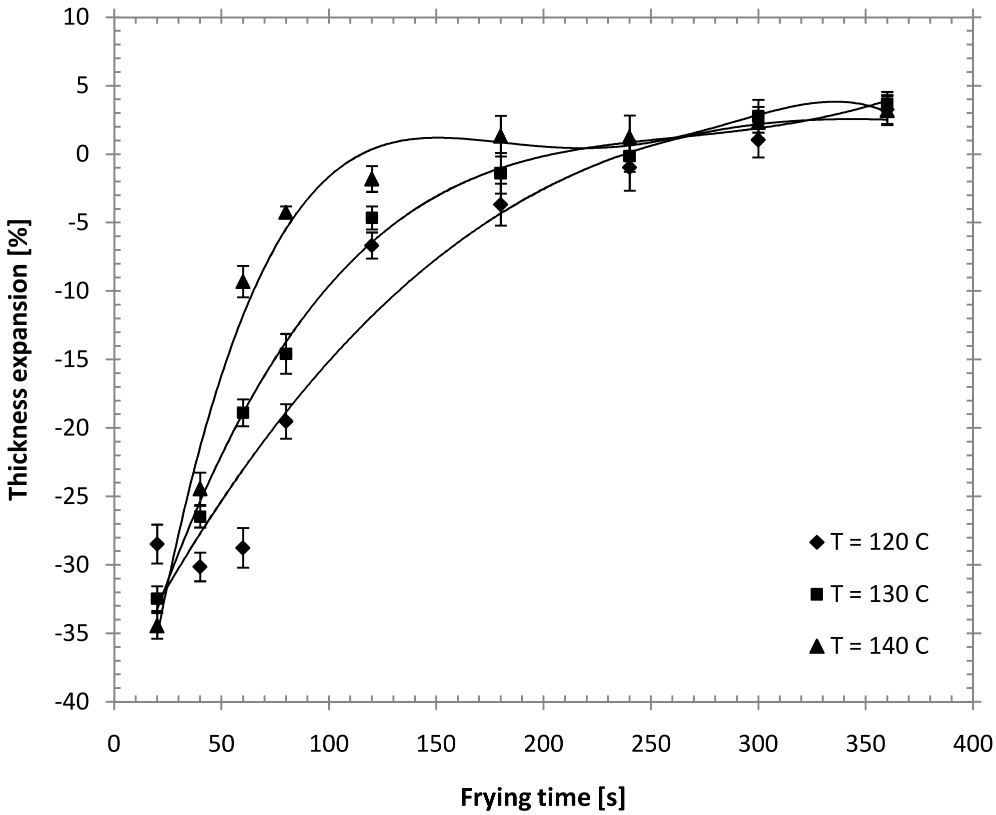


Figure 4-25. Effect of oil temperature on potato chips thickness change, *L*, during vacuum frying. Data were fitted with polynomials. L [%] = 5E-07t^3 - 0.0007t^2 + 0.2997t - 38.627 (120°C); L [%] = -3E-09t^4 + 4E-06t^3 - 0.0023t^2 + 0.5213t - 42.827 (130°C); L [%] = -2E-08t^4 + 2E-05t^3 - 0.0078t^2 + 1.093t - 54.16 (140°C).

4.4. Effect of oil temperature and frying time on thermal properties of potato chips during vacuum frying

4.4.1. Effect of frying time on specific heat of potato chips during vacuum frying

The changes in specific heat of potato chips fried under vacuum at 120°C where studied as a function of frying time. In order to use the equations found in literature for specific heat, a correlation between frying time and moisture content had to be made. This relationship was easily found from the moisture content data previously discussed in Section 4.3.1. The experimental results, as well as the comparison with for specific heat as a function of frying time and moisture content are shown in Figure 4-26 and Figure 4-27, respectively.

Specific heat of the potato chip decreases with temperature as a consequence of moisture loss since it depends greatly on the composition of the sample. At the beginning of the frying time, the specific heat is high since almost three quarter of the sample weight is water. As frying progresses, water in the sample decreases and the overall specific heat is close to the specific heat of the solid matter, carbohydrate.

The two models used to compare the experimental data, supported the idea of great influence of the components of the sample on the specific heat. The correlation between the experimental data and the Riedel (1978) and Heldman and Singh (1981) models were 0.988 and 0.987, respectively, which represents good agreements.

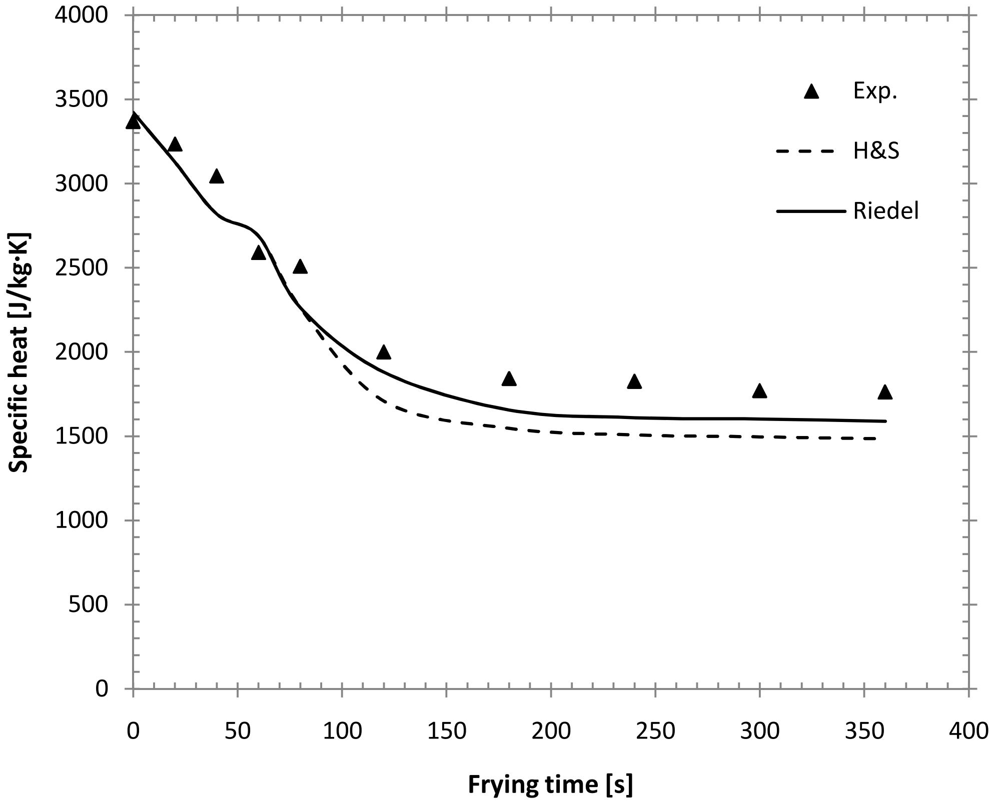


Figure 4-26. Specific heat of potato chips fried under vacuum (1.33 kPa) at 120ºC as a function of frying time.

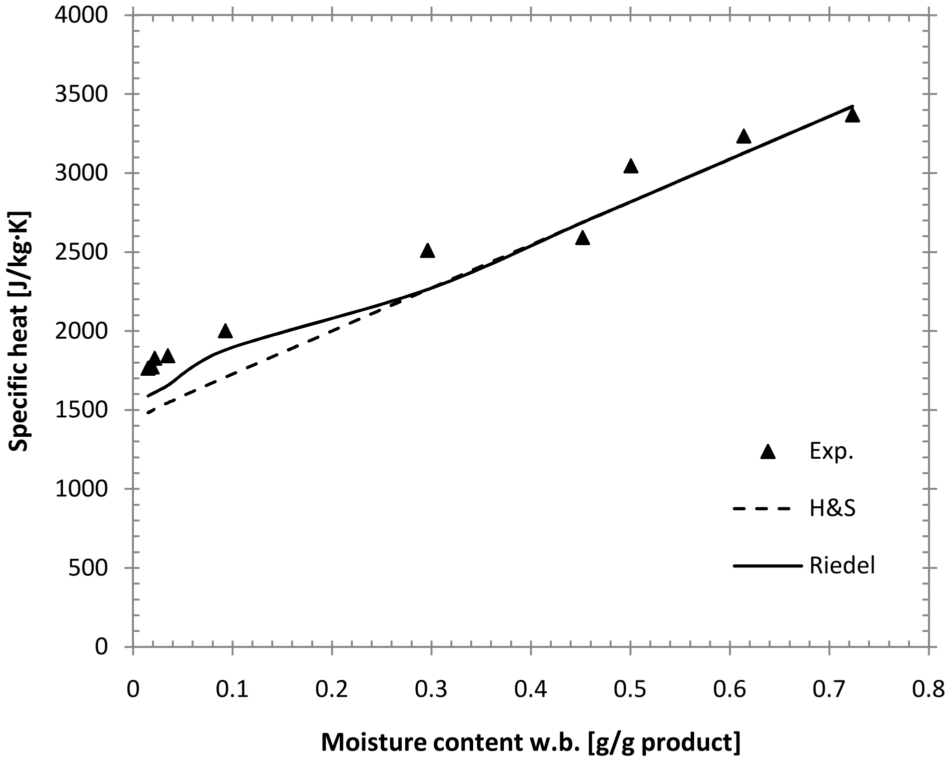


Figure 4-27. Specific heat of potato chips fried under vacuum (1.33 kPa) at 120ºC as a function of moisture content (w.b.).

4.4.2. Effect of oil temperature and frying time on convective heat transfer coefficient potato chips during vacuum frying

4.4.2.1. Surface temperature of potato chips during vacuum frying (*PC*)

The surface temperature of potato chips during vacuum frying at 120, 130, and 140°C was measured with a 0.254-mm diameter thermocouple placed at the potato to oil interface (Figure 4-28). Position of the thermocouple was observed before and after frying to assure the thermocouple maintained the correct place to read temperature. If the thermocouple moved close to the core of the product or was pushed beyond the surface by crust formation, the data was discarded. A surface history that showing a long evaporation period indicated displacement of the thermocouple towards the center of the chip, while displacement beyond the surface was noticeable when the surface temperature history reached the oil temperature almost immediately after potato submersion. The accepted surface temperature history increased from the boiling point at time zero to an asymptote less than the oil temperature in the first 150 s of the frying time. A detailed description of the behavior of the surface temperature of potato chips during vacuum frying is given in Section 4.1.2.

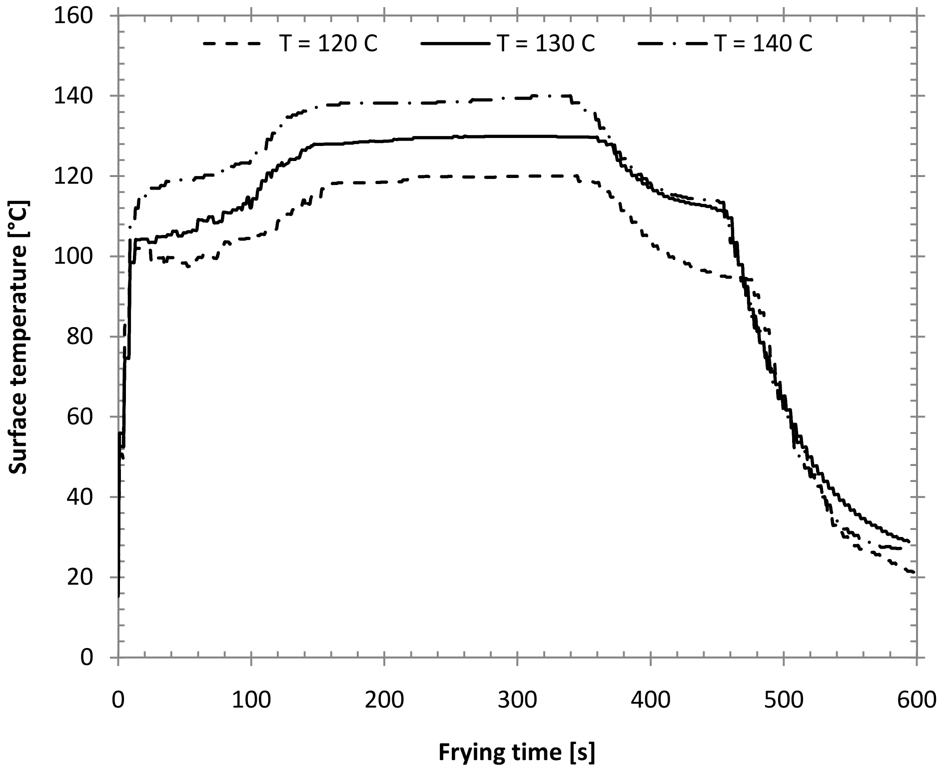


Figure 4-28. Surface temperature history of potato chips (PS) during vacuum frying at different temperatures.

4.4.2.2. Drying rate and surface area of potato chips during vacuum frying

The study of convective heat transfer coefficient was performed for a control mass of one potato slice, which initially weights 3.5 g. The change in water content for this control mass was calculated from the average moisture content data obtained in previous experiments. The change in water mass for one potato chip at different frying temperatures is depicted in Figure 4-29. The curve of water content for each temperature was fitted to an exponential equation in order to obtain the derivative of the curve, which is the drying rate with respect to frying time, *dM/dt*. The exponential equations and their derivatives, and the drying rate curve are shown in Table 4-8, and Figure 4-30, respectively. The rate constant for water loss during frying was directly proportional to the frying temperature; which means that water is evaporated faster at higher temperatures.

Another important variable in the heat transfer coefficient calculation is surface area of the material (Figure 4-31), which was calculated with the diameter data for each frying temperature and, as expected, it follows the same behavior as the diameter shrinkage. The final values of surface area were not different between temperatures; however, the curves have different characteristics during the frying period.

Table 4-8. Fitted exponential equations, and their derivatives, for water content of potato chips during vacuum frying.

Temperature [°C]	**Equation for *M***	$\mathbf{R^2}$	**Equation for *dM/dt***
120	$2.499 \cdot \exp(-0.023t) + 0.015$	0.994	$0.0574 \cdot \exp(-0.023t)$
130	$2.519 \cdot \exp(-0.035t) + 0.011$	0.997	$0.0881 \cdot \exp(-0.035t)$
140	$2.504 \cdot \exp(-0.039t) + 0.008$	0.996	$0.0975 \cdot \exp(-0.039t)$

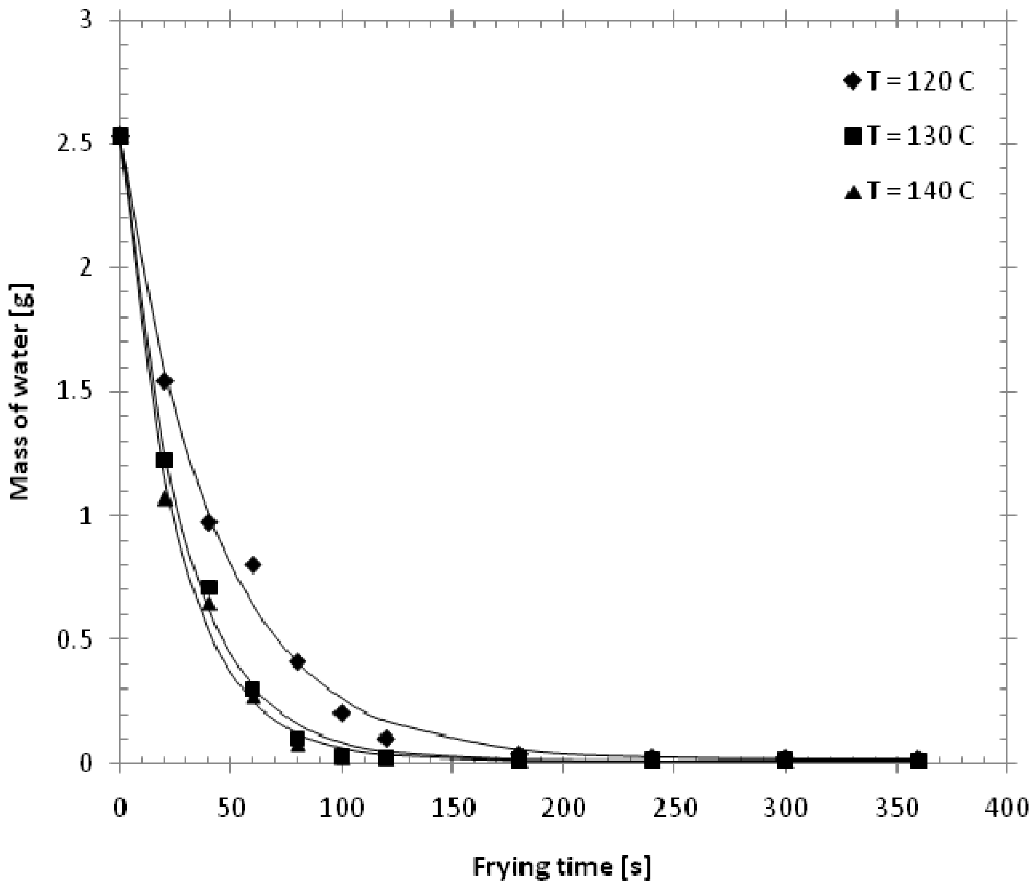


Figure 4-29. Water content of one potato slice during vacuum frying at different temperatures.

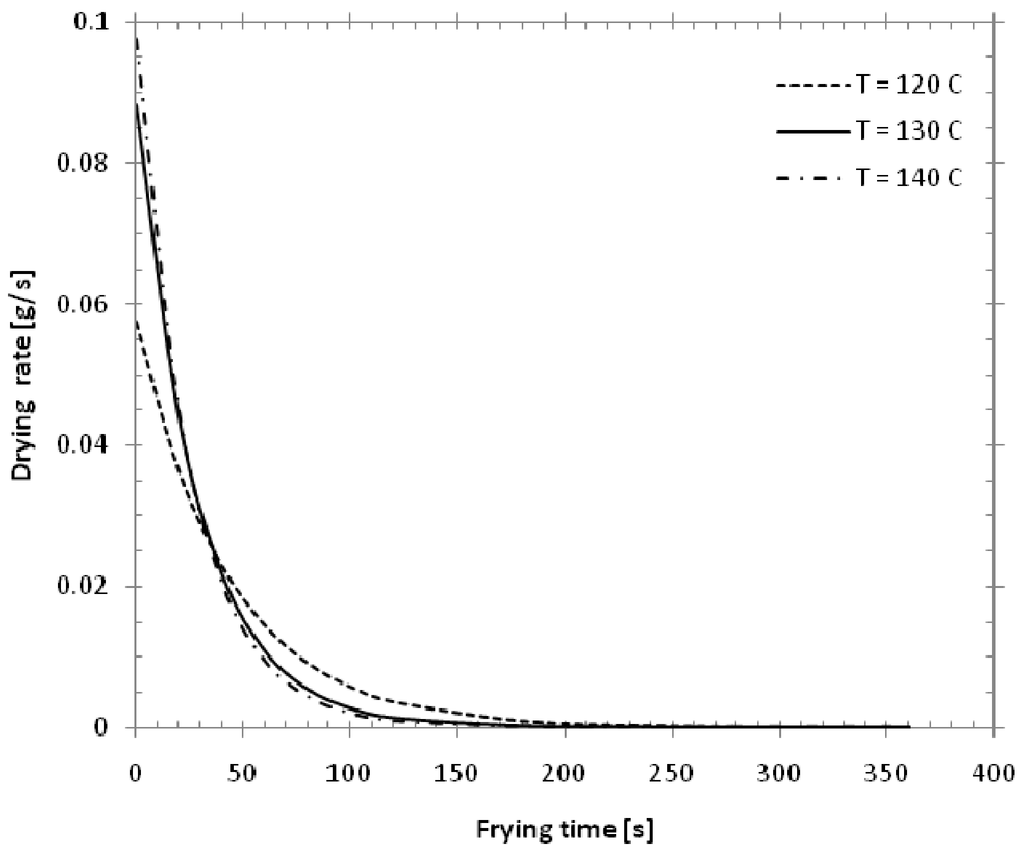


Figure 4-30. Drying rate of one potato slice during vacuum frying at different temperatures.

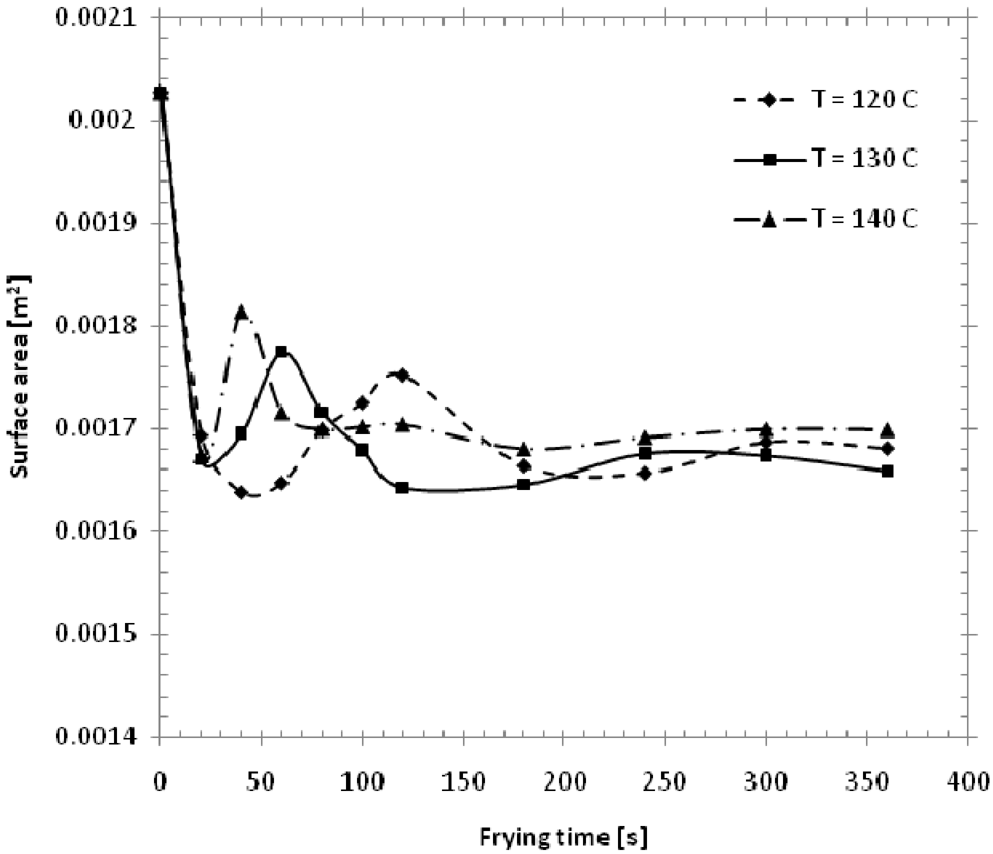


Figure 4-31. Effect of oil temperature on potato chips surface area during vacuum frying. Connecting lines were used to allow a better understanding of experimental data.

4.4.2.3.Convective heat transfer coefficient during vacuum frying of potato chips

All variables needed to determine convective heat transfer coefficient, *h*, during vacuum frying were incorporated into Equation (3-13) to yield the mapping of *h* over the complete boiling period of vacuum frying, Figure 4-32. It is seen on the plot that the heat transfer coefficient has the same trend as the drying rate, and that it changes significantly as a function of frying time. The maximum values of convective heat transfer coefficient were found to be 2,204.8 W/m^2K, 2,523.3 W/m^2K, and 2,649.7 W/m^2K, for 120, 130, and 140 °C, respectively. For the three temperatures, the maximum values of *h* were observed 20 seconds after contact between the potato and the oil. These high values at the beginning of the process are expected, considering that the highest water loss rate also occurs during this initial 20 seconds of the immersion process, along with the rapid increase in surface temperature. It is believed that the initially high rates of heat transfer help to rapidly form the crust matrix before collapse of the dried layer, and a lower, yet still high, rate of heat transfer then allows for cooking of the core region (Hubbard and Farkas, 1999). The minimum values of heat transfer occurred as the equilibrium, and minimum, water content was reached and the drying rate decreased. The boiling period lasted longer at higher temperatures. The values of *h* at the end of the boiling period decreased to 202.8 (240 s), 155.4 (180 s), and 175.8 W/m^2K (120 s), for 120, 130, and 140°C, respectively.

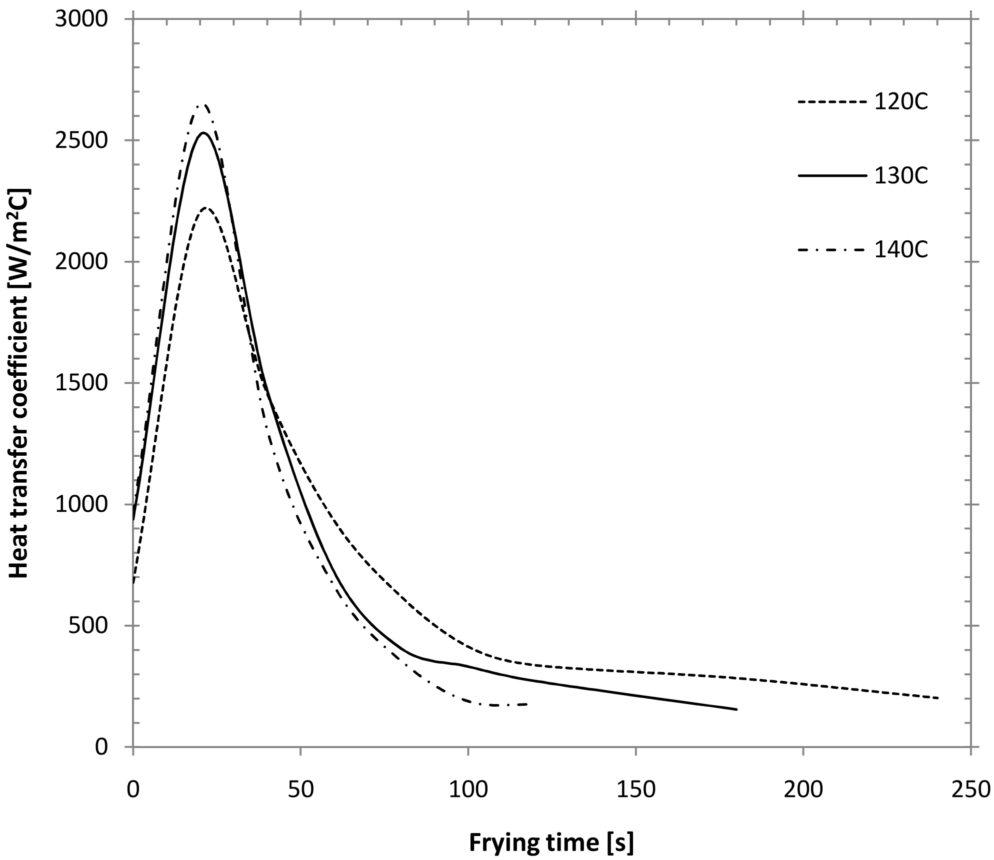


Figure 4-32. Effect of oil temperature on the convective heat transfer coefficient during vacuum frying of potato chips.

CHAPTER V

CONCLUSIONS

The vacuum frying process, at 1.33 kPa and different temperatures (120, 130, 140ºC), was characterized in terms of physical and thermal properties (true and solid density, porosity, heat capacity, and convective heat transfer coefficient), as well as, product quality attributes (oil content, shrinkage, expansion, and microstructure). These parameters are of great importance for the development of a mathematical model able to predict the behavior of the vacuum frying process and product quality changes. Moreover, the effect of a de-oiling system on oil absorption during frying under vacuum was studied.

The main results and conclusions drawn from this work are as follows:

- During vacuum frying at 1.33 kPa for the range of temperature studied, the evaporation temperature of water is between 86 and 94°C, suggesting that the pressure inside the potato chip is higher than the one of the vacuum system.
- A temperature spike of 104°C was seen on the temperature profile of the chip during vacuum frying; this behavior was not observed during traditional frying. This shows that pressure differences within the system causes sudden variations in temperature.
- Moisture loss of potato chips during vacuum frying is faster at higher temperatures and is successfully modeled with a modified equation for moisture diffusion in a flat plate.

- The moisture diffusion coefficient is higher for vacuum frying than for atmospheric frying, and it has a directly proportional relation with the frying temperature which can be modeled with an Arrhenius type equation.
- Potato chips fried at higher temperatures have higher total oil content than those fried at lower temperatures; however, final internal oil content is lower at higher temperatures which means than the de-oiling system is more efficient at the highest temperatures.
- Use of the de-oiling system, before pressurization, removed up to 87% of the surface oil content of potato chips, proving that is a necessary device in order to produce high-quality and healthier snacks.
- Potato chips reduce in diameter by about 10%, and expand thickness by 3% at the end of frying. Fluctuations in diameter values were more pronounced at the lowest temperature.
- Porosity of potato chips increases during frying due decrease in bulk density and increase in true density, which are caused by water loss.
- The microstructure of vacuum-fried potato chips differ from that of the traditionally-fried chips, and it is greatly affected by frying time. Shrinkage of the cells and collapse of the wall, as well as, disruption of starch granules occur as frying progresses.
- Specific heat of potato chips decreases with frying time due to moisture loss during frying. Moreover, the experimental data is well predicted by the Riedel and Heldmand and Singh models.

- The maximum convective heat transfer coefficient of potato chips during vacuum frying is between 2,200 and 2,650 W/m^2K in the temperature range of 120 to 140°C. These values were obtained during the first 20 seconds of frying where the moisture loss rate was highest.

CHAPTER VI

RECOMMENDATIONS FOR FURTHER STUDY

Recommendations for future research on vacuum frying of potato chips include:

- To develop a mathematical model for vacuum frying of potato chips using the parameters determined in this study.
- To conduct sensory analysis test to evaluate consumer perception of low-fat potato chips and somewhat determine the minimum oil content to guarantee consumer acceptability.
- To measure the pressure inside the product in order to understand temperature behavior inside of the chips.
- To implement different microscopy techniques that allow quantification of pores and visualization of oil deposits in the potato chips.
- To develop a new method to measure diameter and thickness in order to reduce large standard deviation.
- To study the effect of temperature on specific heat of potato chips.
- To determine the effect of product load on the convective heat transfer coefficient since this parameter is greatly affected by turbulence.
- To study texture changes during the vacuum frying process.

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APPENDIX A

Table A1. Pressure and temperature profiles during the vacuum frying process at120, 130, and 140 ºC.

	120°C				130°C				140°C			
Time [s]	P [kPa]	PC [°C]	HS [°C]	PS [°C]	P [kPa]	PC [°C]	HS [°C]	PS [°C]	P [kPa]	PC [°C]	HS [°C]	PS [°C]
1	101.6376	20.8324	24.4970	21.0049	101.2633	20.2268	-	-	101.6839	19.2995	23.5412	-
2	101.6376	20.8324	24.4970	21.0049	101.2633	20.2268	-	-	101.6839	19.2995	23.5412	-
3	101.6376	20.8324	24.4970	21.0049	101.2633	20.2268	-	-	101.6839	19.2995	23.5412	-
4	101.6376	20.8324	24.4970	21.0049	101.2633	20.0642	-	-	101.6839	19.3753	25.1372	-
5	101.8689	20.7151	23.7244	21.1811	101.2633	20.0642	-	-	101.6839	19.3753	25.1372	-
6	101.8689	20.7151	23.7244	21.1811	101.2633	20.0642	-	-	101.6839	19.3753	25.1372	-
7	101.8689	20.7151	23.7244	21.1811	101.2633	20.0642	25.4271	-	101.6839	19.3753	25.1372	-
8	101.8689	20.7151	23.7244	21.1811	101.2633	20.0160	25.4271	-	101.5936	19.3597	24.7544	-
9	101.8623	20.5815	23.7305	21.1811	101.2633	20.0160	25.4271	-	101.5936	19.3597	24.7544	-
10	101.8623	20.5815	23.7305	21.5025	101.2633	20.0160	25.6752	-	101.5936	19.3597	24.7544	-
11	101.8623	20.5815	23.7305	21.5025	101.2633	20.0160	25.6752	-	101.5936	19.3597	24.7544	-
12	101.8623	20.5815	23.7305	21.5025	101.2501	19.8431	25.6752	-	101.7037	19.4259	24.2930	-
13	101.8711	20.4712	29.4252	21.3277	101.2501	19.8431	25.6752	-	101.7037	19.4259	24.2930	-
14	101.8711	20.4712	29.4252	21.3277	101.2501	19.8431	25.3167	-	101.7037	19.4259	24.2930	-
15	101.8711	20.4712	29.4252	21.3277	101.2501	19.8431	25.3167	-	101.7037	19.4259	24.2930	-
16	101.8711	20.4712	29.4252	21.3277	101.2677	19.8415	25.3167	19.2978	101.4637	19.4563	23.6501	-
17	101.9041	20.4800	35.6313	21.0241	101.2677	19.8415	25.3167	19.2978	101.4637	19.4563	23.6501	-
18	101.9041	20.4800	35.6313	21.0241	101.2677	19.8415	26.0925	19.2978	101.4637	19.4563	23.6501	-
19	101.9041	20.4800	35.6313	21.0241	101.2677	19.8415	26.0925	19.3192	101.4637	19.4563	23.6501	19.1309
20	101.9041	20.4800	35.6313	21.0241	102.0605	20.3240	26.0925	19.3192	101.4791	19.4873	23.1704	19.1309
21	102.0120	20.6741	40.7650	21.2553	102.0605	20.3240	26.0925	19.3192	101.4791	19.4873	23.1704	19.1309
22	102.0120	20.6741	40.7650	21.2553	102.0605	20.3240	33.0081	19.3192	101.4791	19.4873	23.1704	19.1346
23	102.0120	20.6741	40.7650	21.2553	102.0605	20.3240	33.0081	19.2865	101.4791	19.4873	23.1704	19.1346
24	102.0120	20.6741	40.7650	21.2553	102.2080	20.9877	33.0081	19.2865	101.4879	19.5207	23.2180	19.1346
25	101.9966	20.8901	44.8129	21.8357	102.2080	20.9877	33.0081	19.2865	101.4879	19.5207	23.2180	19.1346

Time	P	PC	HS	PS	P	PC	HS	PS	P	PC	HS	PS
26	101.9966	20.8901	44.8129	21.8357	102.2080	20.9877	40.3455	19.2865	101.4879	19.5207	23.2180	19.0801
27	101.9966	20.8901	44.8129	21.8357	102.2080	20.9877	40.3455	19.1170	101.4879	19.5207	23.2180	19.0801
28	101.9966	20.8901	44.8129	21.8357	102.7145	21.6775	40.3455	19.1170	102.2212	19.8458	26.7220	19.0801
29	101.8050	21.1765	48.5988	22.4131	102.7145	21.6775	40.3455	19.1170	102.2212	19.8458	26.7220	19.0801
30	101.8050	21.1765	48.5988	22.4131	102.7145	21.6775	46.1663	19.1170	102.2212	19.8458	26.7220	19.4887
31	101.8050	21.1765	48.5988	22.4131	102.7145	21.6775	46.1663	19.5508	102.2212	19.8458	26.7220	19.4887
32	101.8050	21.1765	48.5988	22.4131	103.0030	22.3998	46.1663	19.5508	102.2102	20.5226	33.5266	19.4887
33	101.8535	21.4755	51.5671	23.0100	103.0030	22.3998	46.1663	19.5508	102.2102	20.5226	33.5266	19.4887
34	101.8535	21.4755	51.5671	23.0100	103.0030	22.3998	51.5149	19.5508	102.2102	20.5226	33.5266	20.0184
35	101.8535	21.4755	51.5671	23.0100	103.0030	22.3998	51.5149	20.2048	102.2102	20.5226	33.5266	20.0184
36	101.8535	21.4755	51.5671	23.0100	72.6014	23.2951	51.5149	20.2048	103.1087	21.3767	39.8458	20.0184
37	101.7323	21.8489	54.0542	23.7313	72.6014	23.2951	51.5149	20.2048	103.1087	21.3767	39.8458	20.0184
38	101.7323	21.8489	54.0542	23.7313	72.6014	23.2951	55.9830	20.2048	103.1087	21.3767	39.8458	20.5702
39	101.7323	21.8489	54.0542	23.7313	72.6014	23.2951	55.9830	20.9152	103.1087	21.3767	39.8458	20.5702
40	101.7323	21.8489	54.0542	23.7313	49.6301	23.8013	55.9830	20.9152	103.6791	22.1838	46.0024	20.5702
41	101.7125	22.4563	56.2436	23.3556	49.6301	23.8013	55.9830	20.9152	103.6791	22.1838	46.0024	20.5702
42	101.7125	22.4563	56.2436	23.3556	49.6301	23.8013	59.8451	20.9152	103.6791	22.1838	46.0024	21.1268
43	101.7125	22.4563	56.2436	23.3556	49.6301	23.8013	59.8451	21.8704	103.6791	22.1838	46.0024	21.1268
44	101.7125	22.4563	56.2436	23.3556	34.8620	23.9404	59.8451	21.8704	103.9940	22.5933	51.1576	21.1268
45	101.7191	23.1550	55.1955	23.5009	34.8620	23.9404	59.8451	21.8704	103.9940	22.5933	51.1576	21.1268
46	101.7191	23.1550	55.1955	23.5009	34.8620	23.9404	62.2279	21.8704	103.9940	22.5933	51.1576	21.7077
47	101.7191	23.1550	55.1955	23.5009	34.8620	23.9404	62.2279	22.6569	104.2319	22.5933	55.5659	21.7077
48	101.7191	23.1550	55.1955	23.5009	24.8177	24.0011	62.2279	22.6569	104.2319	23.4898	55.5659	21.7077
49	61.5463	23.7283	51.8534	23.4279	24.8177	24.0011	62.2279	22.6569	104.2319	23.4898	55.5659	21.7077
50	61.5463	23.7283	51.8534	23.4279	24.8177	24.0011	59.7277	22.6569	104.2319	23.4898	55.5659	22.3617
51	61.5463	23.7283	51.8534	23.4279	24.8177	24.0011	59.7277	23.1629	104.3486	23.4898	59.4878	22.3617
52	61.5463	23.7283	51.8534	23.4279	17.5240	23.6070	59.7277	23.1629	104.3486	24.3866	59.4878	22.3617

Time	P	PC	HS	PS	P	PC	HS	PS	P	PC	HS	PS
53	43.0190	24.1565	50.1012	23.1148	17.5240	23.6070	59.7277	23.1629	104.3486	24.3866	59.4878	22.3617
54	43.0190	24.1565	50.1012	23.1148	17.5240	23.6070	57.4765	23.1629	104.3486	24.3866	59.4878	22.9890
55	43.0190	24.1565	50.1012	23.1148	17.5240	23.6070	57.4765	23.4322	62.5109	24.3866	59.9149	22.9890
56	43.0190	24.1565	50.1012	23.1148	12.7143	23.1318	57.4765	23.4322	62.5109	25.3900	59.9149	22.9890
57	30.4576	24.6504	49.4628	22.5876	12.7143	23.1318	57.4765	23.4322	62.5109	25.3900	59.9149	22.9890
58	30.4576	24.6504	49.4628	22.5876	12.7143	23.1318	57.4765	23.4322	62.5109	25.3900	59.9149	23.4886
59	30.4576	24.6504	49.4628	22.5876	12.7143	23.1318	57.4765	23.4747	42.7173	25.3900	58.1004	23.4886
60	30.4576	24.6504	49.4628	22.5876	9.3736	22.4866	57.4765	23.4747	42.7173	25.7552	58.1004	23.4886
61	21.6465	24.9542	49.1481	21.7308	9.3736	22.4866	57.4765	23.4747	42.7173	25.7552	58.1004	23.4886
62	21.6465	24.9542	49.1481	21.7308	9.3736	22.4866	57.4765	23.4747	42.7173	25.7552	58.1004	23.8133
63	21.6465	24.9542	49.1481	21.7308	9.3736	22.4866	57.4765	23.2105	29.8079	25.7552	57.2867	23.8133
64	21.6465	24.9542	49.1481	21.5767	7.0833	21.7234	57.4765	23.2105	29.8079	26.2850	57.2867	23.8133
65	15.5178	25.1637	49.3141	21.4767	7.0833	21.7234	57.4765	23.2105	29.8079	26.2850	57.2867	23.8133
66	15.5178	25.1637	49.3141	21.3767	7.0833	21.7234	57.4765	23.2105	29.8079	26.2850	57.2867	24.1196
67	15.5178	25.1637	49.3141	21.2767	7.0833	21.7234	57.4765	23.0206	20.6731	26.2850	57.3127	24.1196
68	15.5178	25.1637	49.3141	21.1767	5.5659	20.9027	56.2345	23.0206	20.6731	26.5545	57.3127	24.1196
69	11.2521	25.0533	50.2918	21.0767	5.5659	20.9027	56.2345	23.0206	20.6731	26.5545	57.3127	24.1196
70	11.2521	25.0533	50.2918	20.9767	5.5659	20.9027	56.2345	23.0206	20.6731	26.5545	57.3127	24.3574
71	11.2521	25.0533	50.2918	20.8767	5.5659	20.9027	56.2345	22.4513	14.7734	26.5545	57.6993	24.3574
72	11.2521	25.0533	50.2918	20.7767	4.5177	20.1959	56.2345	22.4513	14.7734	26.6043	57.6993	24.3574
73	8.4530	24.9364	51.0913	20.6767	4.5177	20.1959	56.2345	22.4513	14.7734	26.6043	57.6993	24.3574
74	8.4530	24.9364	51.0913	20.5767	4.5177	20.1959	56.2345	22.4513	14.7734	26.6043	57.6993	23.7513
75	8.4530	24.9364	51.0913	20.4767	4.5177	20.1959	56.2345	21.8515	10.4482	26.6043	58.4956	23.7513
76	8.4530	24.9364	51.0913	20.3767	3.7998	19.5430	56.2345	21.8515	10.4482	26.8873	58.4956	23.7513
77	6.3962	24.7984	51.7982	20.2767	3.7998	19.5430	56.2345	21.8515	10.4482	26.8873	58.4956	23.7513
78	6.3962	24.7984	51.7982	20.1767	3.7998	19.5430	56.2345	21.8515	10.4482	26.8873	58.4956	23.1515
79	6.3962	24.7984	51.7982	20.0767	3.7998	19.5430	56.2345	20.9440	7.9311	26.8873	59.2554	23.1515

Time	P	PC	HS	PS	P	Center	HS	PS	P	PC	HS	PS
80	6.3962	24.7984	51.7982	19.5767	3.3197	18.8919	56.0846	20.9440	7.9311	26.4492	59.2554	23.1515
81	5.1013	24.4987	52.3456	19.0767	3.3197	18.8919	56.0846	20.9440	7.9311	26.4492	59.2554	23.1515
82	5.1013	24.4987	52.3456	18.5767	3.3197	18.8919	56.0846	20.9440	7.9311	26.4492	59.2554	22.2440
83	5.1013	24.4987	52.3456	18.5767	3.3197	18.8919	56.0846	19.8157	6.0746	26.4492	60.3768	22.2440
84	5.1013	24.4987	52.3456	19.5767	2.9739	18.3204	56.0846	19.8157	6.0746	26.6154	60.3768	22.2440
85	4.0882	24.1860	52.9138	18.4272	2.9739	18.3204	56.0846	19.8157	6.0746	26.6154	60.3768	22.2440
86	4.0882	24.1860	52.9138	18.4272	2.9739	18.3204	56.0846	19.8157	6.0746	26.6154	60.3768	21.1157
87	4.0882	24.1860	52.9138	18.4272	2.9739	18.3204	56.0846	18.6886	4.8568	26.6154	61.5280	21.1157
88	4.0882	24.1860	52.9138	18.4272	2.7515	17.8490	56.0846	18.6886	4.8568	26.7986	61.5280	21.1157
89	3.4034	23.8308	53.5931	17.5355	2.7515	17.8490	56.0846	18.6886	4.8568	26.7986	61.5280	21.1157
90	3.4034	23.8308	53.5931	17.5355	2.7515	17.8490	57.1948	18.6886	4.8568	26.7986	61.5280	19.9886
91	3.4034	23.8308	53.5931	17.5355	2.7515	17.8490	57.1948	17.6363	3.9847	26.7986	62.5120	19.9886
92	3.4034	23.8308	53.5931	17.5355	2.6216	17.4495	57.1948	17.6363	3.9847	26.5512	62.5120	19.9886
93	2.9277	23.3358	54.2563	16.8781	2.6216	17.4495	57.1948	17.6363	3.9847	26.5512	62.5120	19.9886
94	2.9277	23.3358	54.2563	16.8781	2.6216	17.4495	58.8318	17.6363	3.9847	26.5512	62.5120	18.9363
95	2.9277	23.3358	54.2563	16.8781	2.6216	17.4495	58.8318	16.6741	3.3131	26.5512	63.6124	18.9363
96	2.9277	23.3358	54.2563	16.8781	2.4939	17.0521	58.8318	16.6741	3.3131	26.0378	63.6124	18.9363
97	3.2999	31.9099	54.7659	16.4937	2.4939	17.0521	58.8318	16.6741	3.3131	26.0378	63.6124	18.9363
98	3.2999	31.9099	54.7659	16.4937	2.4939	17.0521	61.0705	16.6741	3.3131	26.0378	63.6124	17.9741
99	3.2999	31.9099	54.7659	16.4937	2.4939	17.0521	61.0705	15.9991	2.8616	26.0378	64.5188	17.9741
100	4.2512	50.8067	54.7659	16.4937	2.3793	16.7598	61.0705	15.9991	2.8616	25.3527	64.5188	17.9741
101	4.2512	50.5131	55.5070	50.6515	2.3793	16.7598	61.0705	15.9991	2.8616	25.3527	64.5188	17.9741
102	4.2512	50.5131	55.5070	50.6515	2.3793	16.7598	62.2621	15.9991	2.8616	25.3527	64.5188	17.2991
103	4.2512	50.5131	55.5070	50.6515	2.3793	16.7598	62.2621	15.2767	2.5907	25.3527	65.3257	17.2991
104	4.4450	59.2333	55.5070	49.6515	2.3045	16.5802	62.2621	15.2767	2.5907	24.5133	65.3257	17.2991
105	4.4450	63.4055	60.3345	84.0544	2.3045	16.5802	63.4301	15.2767	2.5907	24.5133	65.3257	17.2991
106	4.4450	63.4055	60.3345	84.0544	2.3045	16.5802	63.4301	15.2767	2.5907	24.5133	65.3257	16.5767

Time	P	PC	HS	PS	P	PC	HS	PS	P	PC	HS	PS
107	4.4450	63.4055	60.3345	84.0544	2.3045	16.5802	63.4301	52.5887	2.3705	24.5133	66.0972	16.5767
108	4.3415	67.1850	60.3345	84.0544	2.2428	16.2998	63.4301	52.5887	2.3705	24.5133	66.0972	16.5767
109	4.3415	88.0955	64.0991	99.6836	2.2428	16.2998	64.7166	52.5887	2.3705	24.5133	66.0972	16.5767
110	4.3415	88.0955	64.0991	99.6836	2.2428	16.2998	64.7166	52.5887	2.3705	24.5133	66.0972	55.8927
111	4.3415	88.0955	64.0991	99.6836	2.2428	16.2998	64.7166	74.6286	4.6432	24.5133	69.3186	55.8927
112	4.3966	89.6045	64.0991	99.6836	2.2648	18.5988	64.7166	74.6286	4.6432	24.4491	69.3186	55.8927
113	4.3966	98.0949	66.6024	101.9521	2.2648	18.5988	65.8078	74.6286	4.6432	24.4491	69.3186	55.8927
114	4.3966	98.0949	66.6024	101.9521	2.2648	18.5988	65.8078	74.6286	4.6432	24.4491	69.3186	74.2936
115	4.3966	98.0949	66.6024	101.9521	2.2648	18.5988	65.8078	98.4664	6.3213	24.4491	73.1902	74.2936
116	4.6564	98.3345	66.6024	101.9521	4.7665	76.5649	65.8078	98.4664	6.3213	24.2406	73.1902	74.2936
117	4.6564	102.7666	68.8918	101.9521	4.7665	76.5649	67.7677	98.4664	6.3213	24.2406	73.1902	74.2936
118	4.6564	102.7666	68.8918	101.9521	4.7665	76.5649	67.7677	98.4664	6.3213	24.2406	73.1902	107.3894
119	4.6564	102.7666	68.8918	101.9521	4.7665	76.5649	67.7677	104.1503	9.0917	25.0753	76.9485	107.3894
120	5.2136	100.5802	68.8918	101.9521	5.4602	93.6484	74.6937	104.1503	9.0917	41.0228	76.9485	107.3894
121	5.2136	95.3003	71.1090	101.9083	5.4602	93.6484	74.6937	104.1503	9.0917	41.0228	76.9485	107.3894
122	5.2136	95.3003	71.1090	101.9083	5.4602	93.6484	74.6937	104.1503	9.0917	41.0228	76.9485	112.0025
123	5.2136	95.3003	71.1090	101.9083	5.4602	93.6484	74.6937	104.2926	10.5451	41.0228	80.5847	112.0025
124	5.6562	91.4253	71.1090	101.9083	5.6915	102.3501	78.7781	104.2926	10.5451	76.6201	80.5847	112.0025
125	5.6562	96.0876	73.0432	98.4192	5.6915	102.3501	78.7781	104.2926	10.5451	76.6201	80.5847	115.5548
126	5.6562	96.0876	73.0432	98.4192	5.6915	102.3501	78.7781	104.2926	10.5451	76.6201	80.5847	115.5548
127	5.6562	96.0876	73.0432	98.9192	5.6915	102.3501	78.7781	104.2926	10.3205	76.6201	83.3832	115.5548
128	5.7245	92.6954	73.0432	98.9192	6.3830	103.5872	81.2615	104.2926	10.3205	92.2502	83.3832	115.5548
129	5.7245	90.3727	74.5685	99.5912	6.3830	103.5872	81.2615	103.4894	10.3205	92.2502	83.3832	115.0548
130	5.7245	90.3727	74.5685	99.5912	6.3830	103.5872	81.2615	103.4894	10.3205	92.2502	83.3832	115.0548
131	5.7245	90.3727	74.5685	99.5912	6.3830	103.5872	81.2615	103.4894	9.6356	92.2502	85.6272	115.0548
132	5.8720	90.6234	74.5685	99.5912	6.6032	96.6708	82.9632	103.4894	9.6356	103.8301	85.6272	115.0548
133	5.8720	89.8231	76.0730	99.5912	6.6032	96.6708	82.9632	103.4894	9.6356	103.8301	85.6272	116.9669

Time	P	PC	HS	PS	P	PC	HS	PS	P	PC	HS	PS
134	5.8720	89.8231	76.0730	99.5912	6.6032	96.6708	82.9632	103.4894	9.6356	103.8301	85.6272	116.9669
135	5.8720	89.8231	76.0730	97.2346	6.6032	96.6708	82.9632	104.9179	8.8560	103.8301	86.9414	116.9669
136	5.7663	88.8358	76.0730	97.2346	6.2707	94.0561	84.6967	104.9179	8.8560	99.7203	86.9414	116.9669
137	5.7663	88.8768	76.9576	99.6390	6.2707	94.0561	84.6967	104.9179	8.8560	99.7203	86.9414	116.9669
138	5.7663	88.8768	76.9576	99.6390	6.2707	94.0561	84.6967	104.9179	8.8560	99.7203	86.9414	116.9669
139	5.7663	88.8768	76.9576	99.6390	6.2707	94.0561	84.6967	104.9237	8.0875	99.7203	87.7399	116.9669
140	5.6298	84.2819	76.9576	99.6390	5.8787	93.6675	85.7037	104.9237	8.0875	97.9374	87.7399	116.9669
141	5.6298	82.5792	77.5771	99.6390	5.8787	93.6675	85.7037	104.9237	8.0875	97.9374	87.7399	117.6317
142	5.6298	82.5792	77.5771	99.6390	5.8787	93.6675	85.7037	104.9237	8.0875	97.9374	87.7399	117.6317
143	5.5021	83.9422	77.5771	99.6390	5.8787	93.6675	85.7037	105.3908	7.3585	97.9374	88.3070	117.6317
144	5.5021	83.9422	77.5771	98.8382	5.2092	94.6324	86.1256	105.3908	7.3585	94.4059	88.3070	117.6317
145	5.5021	83.4917	78.0428	98.8382	5.2092	94.6324	86.1256	105.3908	7.3585	94.4059	88.3070	118.6317
146	5.5021	83.4917	78.0428	98.8382	5.2092	94.6324	86.1256	105.3908	7.3585	94.4059	88.3070	118.6317
147	5.3942	84.8664	78.0428	98.8382	5.2092	94.6324	86.1256	106.2656	6.8807	94.4059	88.5944	118.6317
148	5.3942	84.8664	78.0428	98.3183	5.3611	94.9869	86.3782	106.2656	6.8807	94.7865	88.5944	118.6317
149	5.3942	84.4536	78.2479	98.3183	5.3611	94.9869	86.3782	106.2656	6.8807	94.7865	88.5944	118.6317
150	5.2686	84.2196	78.2479	98.3183	5.3611	94.9869	86.3782	106.2656	6.8807	94.7865	88.5944	118.6317
151	5.2686	84.2196	78.2479	98.3183	5.3611	94.9869	86.3782	105.1273	6.3103	94.7865	88.9652	118.6317
152	5.2686	84.4286	78.2479	97.4700	5.1960	93.7867	86.6230	105.1273	6.3103	94.3295	88.9652	118.6317
153	5.2686	84.4286	78.2912	97.4700	5.1960	93.7867	86.6230	105.1273	6.3103	94.3295	88.9652	118.6317
154	5.1872	84.9875	78.2912	97.4700	5.1960	93.7867	86.6230	105.1273	6.3103	94.3295	88.9652	118.6317
155	5.1872	84.9875	78.2912	97.4700	5.1960	93.7867	86.6230	105.8814	5.9315	94.3295	88.6464	119.0329
156	5.1872	84.7202	78.2912	99.1269	4.9207	92.7261	86.6261	105.8814	5.9315	93.4552	88.6464	119.0329
157	5.0066	84.5376	78.3569	99.1269	4.9207	92.7261	86.6261	105.8814	5.9315	93.4552	88.6464	119.0329
158	5.0066	84.5376	78.3569	99.1269	4.9207	92.7261	86.6261	106.1205	5.9315	93.4552	88.6464	119.0329
159	5.0066	84.5376	78.3569	99.1269	4.9207	92.7261	86.6261	106.1205	5.6628	93.4552	88.5717	119.0329
160	5.0066	84.3198	78.3569	99.7044	4.8568	92.5436	86.4788	106.1205	5.6628	92.0590	88.5717	119.0329

Time	P	PC	HS	PS	P	PC	HS	PS	P	PC	HS	PS
161	4.9119	84.4441	78.5564	99.7044	4.8568	92.5436	86.4788	106.1205	5.6628	92.0590	88.5717	119.0329
162	4.9119	84.4441	78.5564	99.7044	4.8568	92.5436	86.4788	106.5788	5.6628	92.0590	88.5717	119.0329
163	4.9119	84.4441	78.5564	99.7044	4.8568	92.5436	86.4647	106.5044	5.3765	92.0590	88.6471	119.0329
164	4.9119	84.1758	78.5564	100.4286	4.7555	91.5773	86.4647	106.5044	5.3765	93.1182	88.6471	119.0329
165	4.8150	84.5583	78.3362	100.4286	4.7555	91.5773	86.4647	106.5044	5.3765	93.1182	88.6471	119.0329
166	4.8150	84.5583	78.3362	100.4286	4.7555	91.5773	86.6371	109.1296	5.3765	93.1182	88.6471	119.0329
167	4.8150	84.5583	78.3362	100.4286	4.7555	91.5773	86.6371	109.1296	5.0132	93.1182	88.4933	119.5658
168	4.8150	84.0911	78.3362	99.8055	4.6432	91.7645	86.6371	109.1296	5.0132	93.5332	88.4933	119.5658
169	4.7643	84.0329	78.3565	99.8055	4.6432	91.7645	86.5641	109.1296	5.0132	93.5332	88.4933	119.5658
170	4.7643	84.0329	78.3565	99.8055	4.6432	91.7645	86.5641	108.8766	5.0132	93.5332	88.4933	119.5658
171	4.7643	84.0329	78.3565	99.8055	4.6432	91.7645	86.5641	108.8766	4.7467	93.5332	88.3830	119.5658
172	4.7643	84.8591	78.3565	99.4946	4.5375	92.3667	86.5641	108.8766	4.7467	93.9617	88.3830	119.5658
173	4.6432	85.0008	78.2663	99.4946	4.5375	92.3667	86.6400	108.8766	4.7467	93.9617	88.3830	119.5658
174	4.6432	85.0008	78.2663	99.4946	4.5375	92.3667	86.6400	109.8473	4.7467	93.9617	88.3830	120.2144
175	4.6432	85.0008	78.2663	100.4946	4.5375	92.3667	86.6400	109.8473	4.4318	93.9617	88.5887	120.2144
176	4.6432	85.2892	78.2663	102.2845	4.4560	92.6463	86.5667	109.8473	4.4318	94.5233	88.5887	120.2144
177	4.5595	85.1971	78.1237	102.2845	4.4560	92.6463	86.5667	109.8473	4.4318	94.5233	88.5887	120.2144
178	4.5595	85.1971	78.1237	102.2845	4.4560	92.6463	86.5667	108.4065	4.4318	94.5233	88.5887	120.2144
179	4.5595	85.1971	78.1237	102.2845	4.4560	92.6463	86.5667	108.4065	4.1807	94.5233	88.1875	120.2144
180	4.5595	85.2471	78.1237	103.5381	4.2688	93.2054	86.5101	108.4065	4.1807	94.7622	88.1875	120.2144
181	4.3966	85.6423	77.9443	103.5381	4.2688	93.2054	86.5101	108.4065	4.1807	94.7622	88.1875	120.2144
182	4.3966	85.6423	77.9443	103.5381	4.2688	93.2054	86.5101	108.7382	4.1807	94.7622	88.1875	120.4498
183	4.3966	85.6423	77.9443	103.5381	4.2688	93.2054	86.5101	108.7382	3.9209	94.7622	87.6161	120.4498
184	4.3966	83.4567	77.9443	103.0272	4.1675	93.7027	86.4765	108.7382	3.9209	95.4724	87.6161	120.4498
185	4.2820	83.8575	77.9506	104.0272	4.1675	93.7027	86.4765	110.9816	3.9209	95.4724	87.6161	120.4498
186	4.2820	83.8575	77.9506	104.0272	4.1675	93.7027	86.4765	110.9816	3.9209	95.4724	87.6161	120.4498
187	4.2820	83.8575	77.9506	104.0272	4.1675	93.7027	86.4765	110.9816	3.6676	95.4724	87.1263	120.4498

Time	P	PC	HS	PS	P	PC	HS	PS	P	PC	HS	PS
188	4.2820	83.6497	77.9506	104.3271	4.0112	95.0130	86.4486	110.8867	3.6676	95.5444	87.1263	122.3601
189	4.1984	83.8061	77.7721	104.3271	4.0112	95.0130	86.4486	110.8867	3.6676	95.5444	87.1263	122.3601
190	4.1984	83.8061	77.7721	104.3271	4.0112	95.0130	86.4486	110.8867	3.6676	95.5444	87.1263	122.3601
191	4.1984	83.8061	77.7721	104.3271	4.0112	95.0130	86.4486	110.8867	3.4650	95.5444	86.6973	122.3601
192	4.1984	84.9740	77.7721	104.2466	3.8350	95.9764	86.4338	111.5781	3.4650	96.2431	86.6973	122.3601
193	4.0927	85.4868	77.8337	104.2466	3.8350	95.9764	86.4338	111.5781	3.4650	96.2431	86.6973	122.3601
194	4.0927	85.4868	77.8337	104.2466	3.8350	95.9764	86.4338	111.5781	3.4650	96.2431	86.6973	122.3601
195	4.0927	85.4868	77.8337	104.2466	3.8350	95.9764	86.4338	111.5781	3.2734	96.2431	86.5404	122.3601
196	4.0927	86.9525	77.8337	104.4166	3.7183	95.8970	86.2875	112.1364	3.2734	98.5145	86.5404	122.3601
197	4.0640	87.1646	77.8470	104.4166	3.7183	95.8970	86.2875	112.1364	3.2734	98.5145	86.5404	122.9540
198	4.0640	87.1646	77.8470	104.4166	3.7183	95.8970	86.2875	112.1364	3.2734	98.5145	86.5404	122.9540
199	4.0640	87.1646	77.8470	104.4166	3.7183	95.8970	86.2875	111.6364	3.0972	98.5145	86.1274	122.9540
200	4.0640	88.5632	77.8470	104.0319	3.5795	98.0827	86.0907	113.1178	3.0972	98.9138	86.1274	122.9540
201	3.9429	89.0153	77.8600	105.0319	3.5795	98.0827	86.0907	113.1178	3.0972	98.9138	86.1274	123.2231
202	3.9429	89.0153	77.8600	105.0319	3.5795	98.0827	86.0907	113.1178	3.0972	98.9138	86.1274	123.2231
203	3.9429	89.0153	77.8600	105.0319	3.5795	98.0827	86.0907	114.6952	2.8660	98.9138	85.6156	123.2231
204	3.9429	90.4670	77.8600	105.1339	3.4584	100.4352	85.8547	114.6952	2.8660	104.1685	85.6156	123.2231
205	3.8086	90.6915	77.6589	105.1339	3.4584	100.4352	85.8547	112.1952	2.8660	104.1685	85.6156	123.2231
206	3.8086	90.6915	77.6589	105.1339	3.4584	100.4352	85.8547	112.1952	2.8660	104.1685	85.6156	123.2231
207	3.8086	90.6915	77.6589	105.4678	3.4584	100.4352	85.8547	114.3644	2.7823	104.1685	85.3975	123.2231
208	3.7029	93.7765	77.6589	105.4678	3.2734	104.6992	85.6705	114.3644	2.7823	108.5068	85.3975	123.2231
209	3.7029	93.7765	77.3259	105.4678	3.2734	104.6992	85.6705	114.3644	2.7823	108.5068	85.3975	124.8263
210	3.7029	93.7765	77.3259	105.4678	3.2734	104.6992	85.6705	114.3644	2.7823	108.5068	85.3975	124.8263
211	3.7029	95.4769	77.3259	106.3648	3.2734	104.6992	85.6705	116.7852	2.6634	108.5068	85.1789	124.8263
212	3.5994	96.8712	77.3259	106.3648	3.1699	108.6591	85.3183	116.7852	2.6634	111.9789	85.1789	124.8263
213	3.5994	96.8712	77.2178	106.3648	3.1699	108.6591	85.3183	116.7852	2.6634	111.9789	85.1789	126.0224
214	3.5994	96.8712	77.2178	106.3648	3.1699	108.6591	85.3183	118.8334	2.6634	111.9789	85.1789	126.0224

Time	P	PC	HS	PS	P	PC	HS	PS	P	PC	HS	PS
215	3.5135	99.9629	77.2178	106.7176	3.1699	115.6334	85.3183	118.8334	2.5753	111.9789	84.9622	126.0224
216	3.5135	99.9629	77.2178	106.7176	3.0863	115.6334	85.0057	118.8334	2.5753	114.7424	84.9622	126.0224
217	3.5135	99.9629	77.1420	106.7176	3.0863	116.9408	85.0057	118.8334	2.5753	114.7424	84.9622	126.0224
218	3.5135	99.9629	77.1420	106.7176	3.0863	116.9408	85.0057	120.7578	2.5753	114.7424	84.9622	126.0224
219	3.3659	102.5432	77.1420	106.7968	3.0863	116.9408	85.0057	120.7578	2.5137	114.7424	84.8052	126.7487
220	3.3659	102.5432	77.1420	108.7968	2.9761	116.9408	84.6306	120.7578	2.5137	117.7711	84.8052	126.7487
221	3.3659	102.5432	76.9836	108.7968	2.9761	118.1606	84.6306	119.7578	2.5137	117.7711	84.8052	129.0904
222	3.3659	102.5432	76.9836	108.7968	2.9761	118.1606	84.6306	121.4529	2.5137	117.7711	84.8052	129.0904
223	3.3109	104.2761	76.9836	108.8981	2.9761	118.1606	84.6306	121.4529	2.4652	117.7711	84.6657	129.0904
224	3.3109	104.2761	76.9836	109.8981	2.9035	118.1606	84.4097	121.4529	2.4652	120.9574	84.6657	129.0904
225	3.3109	104.2761	76.9051	109.8981	2.9035	119.0147	84.4097	121.4529	2.4652	120.9574	84.6657	130.6429
226	3.3109	104.2761	76.9051	109.8981	2.9035	119.0147	84.4097	122.6935	2.4652	120.9574	84.6657	130.6429
227	3.1809	106.7544	76.9051	110.4857	2.9035	119.0147	84.4040	122.6935	2.4212	120.9574	84.7663	130.6429
228	3.1809	106.7544	76.9051	110.4857	2.9365	119.0147	84.4040	122.6935	2.4212	124.0277	84.7663	130.6429
229	3.1809	106.7544	76.7720	110.4857	2.9365	119.0001	84.4040	123.3935	2.4212	124.0277	84.7663	132.5258
230	3.0532	108.3877	76.7720	110.4857	2.9365	119.0001	84.4040	122.5935	2.4212	124.0277	84.7663	132.5258
231	3.0532	109.0896	76.7720	111.5584	2.9365	119.0001	84.3009	122.7935	2.3837	124.0277	84.8753	132.5258
232	3.0532	109.0896	76.7720	111.5584	2.8176	118.9019	84.3009	122.9935	2.3837	126.7728	84.8753	132.5258
233	2.9563	110.4825	76.6763	111.5584	2.8176	118.9019	84.3009	123.1935	2.3837	126.7728	84.8753	133.2486
234	2.9563	110.4825	76.6763	111.5584	2.8176	118.9019	84.1889	123.3935	2.3837	126.7728	84.8753	133.2486
235	2.9563	110.9683	76.6763	112.5772	2.8176	118.9019	84.1889	124.1935	2.3221	126.7728	85.0659	133.2486
236	2.9233	112.1397	76.6763	112.5772	2.7934	119.3378	84.1889	124.1935	2.3221	128.1096	85.0659	134.6574
237	2.9233	112.1397	76.6035	112.5772	2.7934	119.3378	84.1889	124.1935	2.3221	128.1096	85.0659	134.6574
238	2.9233	112.1397	76.6035	112.5772	2.7934	119.3378	84.1455	124.1935	2.3221	128.1096	85.0659	134.6574
239	2.9233	112.6848	76.6035	113.9379	2.7934	119.3378	84.1455	124.1935	2.2956	128.1096	85.2713	134.6574
240	2.7251	113.4919	76.6035	113.9379	2.7603	119.5229	84.1455	124.5570	2.2956	129.1595	85.2713	135.1833
241	2.7251	113.4919	76.4454	111.6379	2.7603	119.5229	84.1455	124.5570	2.2956	129.1595	85.2713	135.1833

Time	P	PC	HS	PS	P	PC	HS	PS	P	PC	HS	PS
242	2.7251	113.4919	76.4454	113.0322	2.7603	119.5229	84.0655	124.5570	2.2956	129.1595	85.2713	135.1833
243	2.7251	114.0160	76.4454	113.0322	2.7603	119.5229	84.0655	125.5570	2.2604	129.1595	85.2164	135.1833
244	2.8594	114.6201	76.4454	113.0322	2.7934	120.1967	84.0655	126.4859	2.2604	129.9849	85.2164	135.7164
245	2.8594	114.6201	76.4610	114.6799	2.7934	120.1967	84.0655	126.4859	2.2604	129.9849	85.2164	135.7164
246	2.8594	114.6201	76.4610	115.2799	2.7934	120.1967	84.0222	126.4859	2.2604	129.9849	85.2164	135.7164
247	2.8594	115.0206	76.4610	115.2799	2.7141	121.1504	84.0222	126.4859	2.2538	129.9849	85.2735	135.7164
248	2.7845	115.5030	76.4610	115.2799	2.7141	121.1504	84.0222	127.1371	2.2538	130.5593	85.2735	136.1841
249	2.7845	115.5030	76.3833	114.6386	2.7141	121.1504	83.9308	127.1371	2.2538	130.5593	85.2735	136.1841
250	2.7845	115.5030	76.3833	114.6386	2.7141	121.1504	83.9308	127.1371	2.2538	130.5593	85.2735	136.1841
251	2.7845	115.8375	76.3833	114.6386	2.9079	121.5122	83.9308	127.5641	2.2340	130.5593	85.6232	136.1841
252	2.7229	116.0303	76.3833	114.6386	2.9079	121.5122	83.9969	127.5641	2.2340	131.4058	85.6232	136.6888
253	2.7229	116.0303	76.2171	116.7568	2.9079	121.5122	83.9969	127.9641	2.2340	131.4058	85.6232	136.6888
254	2.7229	116.0303	76.2171	116.7568	2.9079	121.5122	83.9969	127.9641	2.2340	131.4058	85.6232	136.6888
255	2.7229	116.4195	76.2171	116.7568	2.9233	122.1129	83.9969	127.9641	2.2120	131.4058	85.7919	137.1291
256	2.6370	116.7503	76.2171	116.7568	2.9233	122.1129	83.8650	127.9641	2.2120	132.0366	85.7919	137.1291
257	2.6370	116.7503	76.0385	117.7067	2.9233	122.1129	83.8650	127.9641	2.2120	132.0366	85.7919	137.1291
258	2.6370	116.7503	76.0385	117.7067	2.9233	122.1129	83.8650	127.9641	2.2120	132.0366	85.7919	137.1291
259	2.6370	117.0149	76.0385	117.7067	2.8726	122.5676	83.8650	127.9641	2.1679	132.0366	85.7037	137.7031
260	2.5775	117.1183	76.0385	117.7067	2.8726	122.5676	83.7595	127.9641	2.1679	132.5343	85.7037	137.7031
261	2.5775	117.1183	75.9822	118.1441	2.8726	122.5676	83.7595	128.0038	2.1679	132.5343	85.7037	137.7031
262	2.5775	117.1183	75.9822	118.1441	2.8682	122.5676	83.7595	128.0038	2.1679	132.5343	85.7037	137.7031
263	2.5775	117.3471	75.9822	118.1441	2.8682	122.7583	83.7595	128.0038	2.1305	132.5343	86.0339	137.7031
264	2.4982	117.3557	75.9822	118.1441	2.8682	122.7583	83.7334	128.0038	2.1305	133.1544	86.0339	137.7031
265	2.4982	117.3557	75.8212	118.2936	2.8682	122.7583	83.7334	128.0038	2.1305	133.1544	86.0339	137.7031
266	2.4982	117.3557	75.8212	118.2936	2.8528	122.7583	83.7334	128.0352	2.1305	133.1544	86.0339	137.7031
267	2.4982	117.6802	75.8212	118.2936	2.8528	122.9276	83.7334	128.0352	2.0732	133.4439	85.9729	137.7031
268	2.4740	117.8143	75.8212	118.2936	2.8528	122.9276	83.7052	128.0352	2.0732	133.6510	85.9729	137.7031

Time	P	PC	HS	PS	P	PC	HS	PS	P	PC	HS	PS
269	2.4740	117.8143	75.6957	118.2936	2.8528	122.9276	83.7052	128.0352	2.0732	133.6510	85.9729	137.7031
270	2.4740	117.8143	75.6957	118.2936	2.8220	122.9276	83.7052	128.0352	2.0732	133.6510	85.9729	137.7031
271	2.4586	118.2319	75.6957	118.2936	2.8220	123.2428	83.7052	128.0352	2.0512	133.8613	86.2751	137.7031
272	2.4586	118.2319	75.6957	118.2936	2.8220	123.2428	83.6172	128.0352	2.0512	134.0454	86.2751	137.7031
273	2.4586	118.2363	75.5975	118.2936	2.8220	123.2428	83.6172	128.0352	2.0512	134.0454	86.2751	137.7031
274	2.4586	118.2363	75.5975	118.2936	2.7890	123.2428	83.6172	128.0352	2.0512	134.0454	86.2751	137.7031
275	2.4234	118.3190	75.5975	118.2936	2.7890	123.7980	83.6172	128.0352	2.0049	134.1761	86.4843	137.7031
276	2.4234	118.3190	75.5975	118.2936	2.7890	123.7980	83.5996	128.2352	2.0049	134.2750	86.4843	138.1886
277	2.4234	118.3190	75.6070	118.2936	2.7890	123.7980	83.5996	128.2352	2.0049	134.2750	86.4843	138.1886
278	2.4234	118.3190	75.6070	118.2936	2.7273	123.7980	83.5996	128.2352	2.0049	134.2750	86.4843	138.1886
279	2.3727	118.3804	75.6070	118.2936	2.7273	124.1377	83.5996	128.2352	1.9587	134.4961	86.6015	138.1886
280	2.3727	118.3804	75.6070	118.2936	2.7273	124.1377	83.6953	128.2352	1.9587	134.7696	86.6015	138.1886
281	2.3727	118.3804	75.8052	118.2936	2.7273	124.1377	83.6953	128.2352	1.9587	134.7696	86.6015	138.1886
282	2.3727	118.3804	75.8052	118.2936	2.7009	124.1377	83.6953	128.2352	1.9587	134.7696	86.6015	138.1886
283	2.3353	118.3195	75.8052	118.2936	2.7009	124.6159	83.6953	128.4333	1.9191	134.9295	86.6529	138.1886
284	2.3353	118.3195	75.8052	118.2936	2.7009	124.6159	83.7683	128.4333	1.9191	135.0604	86.6529	138.1886
285	2.3353	118.3195	75.8306	118.2936	2.7009	124.6159	83.7683	128.4333	1.9191	135.0604	86.6529	138.1886
286	2.3089	118.5509	75.8306	118.2936	2.6304	124.6159	83.7683	128.4333	1.9191	135.0604	86.6529	138.1886
287	2.3089	118.5509	75.8306	118.2936	2.6304	125.0399	83.7683	128.5488	1.8640	135.3546	87.0065	138.1886
288	2.3089	118.5509	75.8306	118.2936	2.6304	125.0399	83.7934	128.5488	1.8640	135.4457	87.0065	138.1886
289	2.3089	118.5509	75.8830	118.2936	2.6304	125.0399	83.7934	128.5488	1.8640	135.4457	87.0065	138.1886
290	2.3067	118.5673	75.8830	118.3926	2.5841	125.0399	83.7934	128.5488	1.8640	135.4457	87.0065	138.1886
291	2.3067	118.5673	75.8830	118.3926	2.5841	125.0028	83.9317	128.5589	1.8332	135.6443	87.0186	138.1886
292	2.3067	118.5673	75.8830	118.3926	2.5841	125.0028	83.9317	128.5589	1.8332	135.9114	87.0186	138.1886
293	2.2648	118.6257	76.0844	118.3926	2.5841	125.0028	83.9317	128.5589	1.8332	135.9114	87.0186	138.1886
294	2.2648	118.6257	76.0844	118.3926	2.5115	125.0028	83.9317	128.5589	1.8332	135.9114	87.0186	138.1886
295	2.2648	118.6257	76.0844	118.3926	2.5115	125.4615	83.8374	128.7670	1.7649	136.0956	87.1775	138.1886

Time	P	PC	HS	PS	P	PC	HS	PS	P	PC	HS	PS
296	2.2648	118.6257	76.0844	118.3926	2.5115	125.4615	83.8374	128.7670	1.7649	136.1296	87.1775	138.1886
297	2.2252	118.5909	76.5511	118.3926	2.5115	125.4615	83.8374	128.7670	1.7649	136.1296	87.1775	138.1886
298	2.2252	118.5909	76.5511	118.4803	2.4432	125.7401	83.8364	128.7670	1.7649	136.1296	87.1775	138.1886
299	2.2252	118.5909	76.5511	118.4803	2.4432	125.7401	83.8364	128.6750	1.7032	136.2558	87.3272	138.1886
300	2.2252	118.5909	76.5511	118.4803	2.4432	125.7401	83.8364	128.6750	1.7032	136.3715	87.3272	138.1886
301	2.2186	118.5622	76.8742	118.4803	2.4432	125.7401	83.8364	128.6750	1.7032	136.3715	87.3272	138.1886
302	2.2186	118.5622	76.8742	118.4803	2.3705	125.9005	83.7326	128.6930	1.7032	136.3715	87.3272	138.1886
303	2.2186	118.5622	76.8742	118.4803	2.3705	125.9005	83.7326	128.6930	1.6592	136.4627	87.3322	138.1886
304	2.2186	118.5622	76.8742	118.4803	2.3705	125.9005	83.7326	128.6930	1.6592	136.6843	87.3322	138.1886
305	2.1855	118.5741	77.3254	118.4803	2.3705	125.9005	84.0131	128.6930	1.6592	136.6843	87.3322	138.1886
306	2.1855	118.5741	77.3254	118.4803	2.3331	126.3256	84.0131	128.7464	1.6592	136.6843	87.3322	138.1886
307	2.1855	118.5741	77.3254	118.4803	2.3331	126.3256	84.0131	128.7464	1.5975	136.8048	87.3580	138.1886
308	2.1855	118.5741	77.3254	118.4803	2.3331	126.3256	84.0131	128.7464	1.5975	136.8904	87.3580	138.1886
309	2.1349	118.6550	77.5214	118.4803	2.3331	126.3256	84.1624	128.7464	1.5975	136.8904	87.3580	138.1886
310	2.1349	118.6550	77.5214	118.5363	2.2604	126.5090	84.1624	128.8275	1.5975	136.8904	87.3580	138.1886
311	2.1349	118.6550	77.5214	118.5363	2.2604	126.5090	84.1624	128.8275	1.5557	137.0450	87.5060	138.1886
312	2.1349	118.6550	77.5214	118.5363	2.2604	126.5090	84.3332	128.8275	1.5557	137.2113	87.5060	138.1886
313	2.1195	118.7121	77.6630	118.5363	2.2032	126.5090	84.3332	129.1780	1.5557	137.2113	87.5060	138.1886
314	2.1195	118.7121	77.6630	118.9941	2.2032	126.7633	84.3332	129.1780	1.5557	137.2113	87.5060	138.1886
315	2.1195	118.7121	77.6630	118.9941	2.2032	126.7633	84.3332	129.1780	1.5227	137.4336	87.5162	138.1886
316	2.1327	118.6416	77.6630	118.9941	2.2032	126.7633	84.7325	129.1780	1.5227	137.5057	87.5162	138.1886
317	2.1327	118.6416	77.7205	118.9941	2.1371	126.7633	84.7325	129.2425	1.5227	137.5057	87.5162	138.1886
318	2.1327	118.6416	77.7205	119.2229	2.1371	127.2470	84.7325	129.2425	1.5227	137.5057	87.5162	138.1886
319	2.1327	118.6416	77.7205	119.2229	2.1371	127.2470	84.7325	129.2425	1.5711	137.7850	87.5021	138.1886
320	2.0424	118.7664	77.7205	119.2229	2.1371	127.2470	85.0537	129.2425	1.5711	137.9367	87.5021	138.1886
321	2.0424	118.7664	78.2034	119.2229	2.0622	127.2470	85.0537	129.2425	1.5711	137.9367	87.5021	138.1886
322	2.0424	118.7664	78.2034	119.4816	2.0622	127.3993	85.0537	129.2425	1.5711	137.9367	87.5021	138.1886

Time	P	PC	HS	PS	P	PC	HS	PS	P	PC	HS	PS
323	2.0424	118.7664	78.2034	119.4816	2.0622	127.3993	85.0537	129.2425	1.5623	138.0492	87.4997	138.1886
324	1.9895	118.7045	78.2034	119.4816	2.0622	127.3993	85.8138	129.2425	1.5623	138.3784	87.4997	138.1886
325	1.9895	118.7045	78.0660	119.4816	2.0160	127.3993	85.8138	129.2425	1.5623	138.3784	87.4997	138.1886
326	1.9895	118.7045	78.0660	119.8122	2.0160	127.6359	85.8138	129.2425	1.5623	138.3784	87.4997	138.1886
327	1.9895	118.7045	78.0660	119.8122	2.0160	127.6359	85.8138	129.2425	1.5799	138.5235	87.5378	138.1886
328	1.9345	118.6762	78.0660	119.8122	2.0160	127.6359	86.2075	129.5947	1.5799	138.4938	87.5378	138.1886
329	1.9345	118.6762	77.7790	119.8122	2.1811	127.6359	86.2075	129.5947	1.5799	138.4938	87.5378	138.1886
330	1.9345	118.6762	77.7790	119.8565	2.1811	128.0491	86.2075	129.5947	1.5799	138.4938	87.5378	138.1886
331	1.9345	118.6762	77.7790	119.8565	2.1811	128.0491	86.2075	129.5947	1.5315	138.6017	87.5454	138.1886
332	1.8618	118.6483	77.7790	119.8565	2.1811	128.0491	86.2002	129.5947	1.5315	138.7147	87.5454	138.1886
333	1.8618	118.6483	77.6351	119.8565	1.8662	128.0491	86.2002	129.5947	1.5315	138.7147	87.5454	138.1886
334	1.8618	118.6483	77.6351	119.8452	1.8662	128.4565	86.2002	129.5947	1.5315	138.7147	87.5454	138.1886
335	1.8618	118.6483	77.6351	119.8452	1.8662	128.4565	86.4256	129.5947	1.5095	138.8361	87.4986	138.1886
336	1.8222	118.6718	77.6351	119.8452	1.8662	128.4565	86.4256	129.5947	1.5095	139.0076	87.4986	138.1886
337	1.8222	118.6718	77.4499	119.8452	1.8662	128.4565	86.4256	129.5947	1.5095	139.0076	87.4986	138.1886
338	1.8222	118.6718	77.4499	119.8040	1.8662	128.7392	86.4256	129.5947	1.5095	139.0076	87.4986	138.1886
339	1.8222	118.6718	77.4499	119.8040	1.8662	128.7392	86.3419	129.5947	1.4896	138.9947	87.5450	138.1886
340	1.9785	118.6046	77.4499	119.8040	1.8662	128.7392	86.3419	129.5947	1.4896	139.0534	87.5450	138.1886
341	1.9785	118.6046	77.3871	119.8040	1.8090	128.7392	86.3419	129.5947	1.4896	139.0534	87.5450	138.1886
342	1.9785	118.6046	77.3871	119.7999	1.8090	128.8947	86.3419	129.5947	1.4896	139.0534	87.5450	138.1886
343	1.9455	118.6442	77.3871	119.7999	1.8090	128.8947	86.3153	129.5947	1.5031	139.0421	87.4899	138.1886
344	1.9455	118.6442	77.3871	119.7999	1.8090	128.8947	86.3153	129.5947	1.5031	139.0865	87.4899	138.1886
345	1.9455	118.6442	77.5253	119.7999	1.7715	128.8947	86.3153	129.5947	1.5031	139.0865	87.4899	138.1886
346	1.9455	118.6442	77.5253	119.7965	1.7715	129.1816	86.3153	129.5947	1.5031	139.0865	87.4899	138.1886
347	1.8684	118.7786	77.5253	119.7965	1.7715	129.1816	86.7085	129.5947	1.4811	139.0642	87.4004	138.1886
348	1.8684	118.7786	77.5253	119.8784	1.7715	129.1816	86.7085	129.5947	1.4811	139.1846	87.4004	138.1886
349	1.8684	118.7786	78.0791	119.8784	1.8508	129.1816	86.7085	129.5947	1.4811	139.1846	87.4004	138.4886

Time	P	PC	HS	PS	P	PC	HS	PS	P	PC	HS	PS
350	1.7913	118.6971	78.0791	119.8784	1.8508	129.5895	86.7085	129.5947	1.4811	139.1846	87.4004	138.4886
351	1.7913	118.6971	78.0791	119.8784	1.8508	129.5895	86.5436	129.5947	1.4480	139.2392	87.2806	138.4886
352	1.7913	118.6971	78.0791	119.7783	1.8508	129.5895	86.5436	129.5947	1.4480	139.3445	87.2806	138.4886
353	1.7913	118.6971	78.2825	119.7783	1.9345	129.5895	86.5436	129.5947	1.4480	139.3445	87.2806	138.4886
354	1.4720	118.6351	78.2825	119.7783	1.9345	129.7601	86.5436	129.5947	1.4480	139.3445	87.2806	138.4886
355	1.4720	118.6351	78.2825	119.7783	1.9345	129.7601	86.6817	129.5947	1.4194	139.2770	87.2927	138.4886
356	1.4720	118.6351	78.2825	119.7914	1.9345	129.6601	86.6817	129.5947	1.4194	139.3169	87.2927	138.4886
357	1.6856	118.6566	78.6479	119.7914	1.7099	129.6601	86.6817	129.5947	1.4194	139.3169	87.2927	138.4886
358	1.6856	118.6566	78.6479	119.7914	1.7099	129.6601	86.6817	129.9153	1.4194	139.3169	87.2927	138.4886
359	1.6856	118.6566	78.6479	119.7914	1.7099	129.6601	86.7464	129.9153	1.3599	139.2943	87.2836	138.4886
360	1.6856	118.6566	78.6479	119.7300	1.7099	129.6601	86.7464	129.9153	1.3599	139.4144	87.2836	138.4886
361	1.6152	118.7466	78.3534	119.7300	1.8640	129.6601	86.7464	129.9153	1.3599	139.4144	87.2836	138.4886
362	1.6152	118.7466	78.3534	119.7300	1.8640	129.6601	86.9384	129.6782	1.3599	139.4144	87.2836	138.4886
363	1.6152	118.7466	78.3534	119.7300	1.8640	129.6601	86.9384	129.6782	1.3776	139.4875	87.0991	138.4886
364	1.5997	118.6231	78.3534	119.7408	1.8640	129.6601	86.9384	129.6782	1.3776	139.5643	87.0991	138.4886
365	1.5997	118.6231	78.3059	119.7408	1.8310	129.6601	86.9384	129.6782	1.3776	139.5643	87.0991	138.4886
366	1.5997	118.6231	78.3059	119.7408	1.8310	129.6601	86.8850	129.9679	1.3776	139.5643	87.0991	138.4886
367	1.5997	118.6231	78.3059	119.7408	1.8310	129.6601	86.8850	129.9679	1.4458	139.5023	87.1857	138.4886
368	1.5447	118.4467	78.3059	119.5479	1.8310	129.6601	86.8850	129.8679	1.4458	139.4181	87.1857	138.4886
369	1.5447	118.4467	78.2150	119.5479	1.8596	129.6601	86.6505	129.8679	1.4458	139.4181	87.1857	138.4886
370	1.5447	118.4467	78.2150	119.5479	1.8596	129.6601	86.6505	129.8679	1.4458	139.4181	87.1857	138.4886
371	1.5447	118.4467	78.2150	119.5479	1.8596	129.6601	86.6505	129.8679	1.5361	139.3660	87.3297	138.4886
372	1.5315	118.6298	78.2150	119.5619	1.8596	129.6601	86.6505	129.8679	1.5361	139.3207	87.3297	138.4886
373	1.5315	118.6298	78.1850	119.5619	1.8244	129.6824	86.6988	129.8679	1.5361	139.3207	87.3297	138.4886
374	1.5315	118.6298	78.1850	119.7619	1.8244	129.6824	86.6988	129.8679	1.5361	139.3207	87.3297	138.4886
375	1.5315	118.6298	78.1850	119.7619	1.8244	129.6824	86.6988	129.8679	1.5405	139.3134	87.3272	138.9886
376	1.5095	118.9817	78.1850	119.6737	1.8244	129.6824	86.4348	129.8679	1.5405	139.3414	87.3272	138.9886

Time	P	PC	HS	PS	P	PC	HS	PS	P	PC	HS	PS
377	1.5095	118.9817	78.1631	119.6737	1.8156	129.6824	86.4348	129.8679	1.5405	139.3414	87.3272	138.9886
378	1.5095	118.9817	78.1631	119.6737	1.8156	129.6824	86.4348	129.8679	1.5405	139.3414	87.3272	138.9886
379	1.5095	118.9817	78.1631	119.6737	1.8156	129.6824	86.4348	129.8679	1.5009	139.3619	87.1217	138.9886
380	1.5117	119.3689	78.1631	119.6737	1.8156	129.6824	86.5899	129.8679	1.5009	139.3925	87.1217	138.9886
381	1.5117	119.3689	78.0656	119.6737	1.7913	129.6824	86.5899	129.8679	1.5009	139.3925	87.1217	138.9886
382	1.5117	119.3689	78.0656	119.6737	1.7913	129.6824	86.5899	129.9679	1.5009	139.3925	87.1217	138.9886
383	1.5117	119.3689	78.0656	119.6737	1.7913	129.6824	86.5899	129.9679	1.4899	139.3957	87.1023	138.9886
384	1.4852	119.7666	78.0656	119.8737	1.7913	129.6824	86.6947	129.9679	1.4899	139.4415	87.1023	138.9886
385	1.4852	119.7666	78.0711	119.8737	1.7913	129.6824	86.6947	129.9679	1.4899	139.4415	87.1023	138.9886
386	1.4852	119.7666	78.0711	119.8737	1.7913	129.6824	86.6947	129.9679	1.4899	139.4415	87.1023	138.9886
387	1.4852	119.7666	78.0711	119.8737	1.7913	129.6824	86.6947	129.9679	1.4612	139.3668	87.0333	138.9886
388	1.4588	119.7766	78.0711	119.8737	1.7913	129.6824	86.8371	129.9679	1.4612	139.3884	87.0333	138.9886
389	1.4588	119.7866	78.0516	119.8737	1.7649	129.6824	86.8371	129.9679	1.4612	139.3884	87.0333	138.9886
390	1.4588	119.7926	78.0516	119.8737	1.7649	129.8287	86.8371	129.9679	1.4612	139.3884	87.0333	138.9886
391	1.4588	119.7986	78.0516	119.8737	1.7649	129.8287	86.9403	129.9679	1.4568	139.4422	87.1266	138.9886
392	1.4434	119.8046	78.0516	119.8737	1.7649	129.8287	86.9403	129.9679	1.4568	139.4217	87.1266	138.9886
393	1.4434	119.8106	77.8996	119.8737	1.7429	129.8287	86.9403	129.9679	1.4568	139.4217	87.1266	138.9886
394	1.4434	119.8166	77.8996	119.8737	1.7429	129.8287	86.9403	129.9679	1.4568	139.4217	87.1266	138.9886
395	1.4434	119.8226	77.8996	119.8737	1.7429	129.8287	86.9111	129.9679	1.4392	139.3678	87.2151	138.9886
396	1.4522	119.8286	77.8996	119.8737	1.7319	129.8287	86.9111	129.9679	1.4392	139.3858	87.2151	138.9886
397	1.4522	119.8346	77.8023	119.8737	1.7319	129.8287	86.9111	129.9679	1.4392	139.3858	87.2151	139.3886
398	1.4522	119.8406	77.8023	119.8737	1.7319	129.8287	86.9111	129.9679	1.4392	139.3858	87.2151	139.3886
399	1.4522	119.8466	77.8023	119.8737	1.7319	129.8287	87.3006	129.9679	1.4106	139.3475	87.3051	139.3886
400	1.4500	119.8526	77.8023	119.8737	1.6614	129.8287	87.3006	129.9124	1.4106	139.3001	87.3051	139.3886
401	1.4500	119.8586	77.8378	119.8737	1.6614	129.8287	87.3006	129.9124	1.4106	139.3001	87.3051	139.3886
402	1.4500	119.8646	77.8378	119.8737	1.6614	129.8287	87.3006	129.9124	1.4106	139.3001	87.3051	139.3886
403	1.4500	119.8706	77.8378	119.8737	1.6614	129.8287	87.1607	129.9124	1.3533	139.3097	87.1518	139.3886

Time	P	PC	HS	PS	P	PC	HS	PS	P	PC	HS	PS
404	1.4280	119.8766	77.8378	119.8737	1.6900	129.8287	87.1607	129.9124	1.3533	139.2695	87.1518	139.3886
405	1.4280	119.8826	77.6456	119.8737	1.6900	129.8287	87.1607	129.9124	1.3533	139.2695	87.1518	139.3886
406	1.4280	119.8886	77.6456	119.8737	1.6900	129.8287	87.1607	129.9124	1.3533	139.2695	87.1518	139.3886
407	1.4059	119.8946	77.6456	119.8737	1.6900	129.8287	87.1348	129.9124	1.3599	139.2748	87.1219	139.3886
408	1.4059	119.9006	77.6456	119.8737	1.6724	129.8287	87.1348	129.9124	1.3599	139.2099	87.1219	139.3886
409	1.4059	119.9066	77.5191	119.9647	1.6724	129.8287	87.1348	129.9124	1.3599	139.2099	87.1219	139.3886
410	1.4059	119.9126	77.5191	119.9647	1.6724	129.8287	87.1348	129.9124	1.3599	139.2099	87.1219	139.3886
411	1.4081	119.9186	77.5191	119.9647	1.6724	129.8287	86.9930	129.9124	1.3599	139.1814	87.1260	139.3886
412	1.4081	119.9246	77.5191	119.9647	1.8728	129.8287	86.9930	129.9124	1.3599	139.1837	87.1260	139.3886
413	1.4081	119.9306	77.4373	119.9647	1.8728	129.8287	86.9930	129.9124	1.3599	139.1837	87.1260	139.3886
414	1.3707	119.9366	77.4373	119.9647	1.8728	129.8287	86.9930	129.9124	1.3599	139.1837	87.1260	139.3886
415	1.3707	119.9426	77.4373	119.9647	1.8728	129.8287	86.9699	129.9124	1.3497	139.1747	87.0533	139.3886
416	1.3707	119.9486	77.4373	119.9647	1.9081	129.8287	86.9699	129.9124	1.3497	139.1754	87.0533	139.3886
417	1.3465	119.9546	77.3353	119.9647	1.9081	129.8287	86.9699	129.9124	1.3497	139.1754	87.0533	139.3886
418	1.3465	119.9606	77.3353	119.9647	1.9081	129.8287	86.9699	129.9124	1.3497	139.1754	87.0533	139.3886
419	1.3465	119.9666	77.3353	119.9647	1.9081	129.8287	86.8857	129.9124	1.3563	139.1488	87.0125	139.3886
420	1.3465	119.9726	77.3353	119.9647	1.8706	129.8287	86.8857	129.9124	1.3563	139.1488	87.0125	139.9814
421	1.3443	119.9786	77.3886	119.9647	1.8706	129.8287	86.8857	129.9124	1.3563	139.1488	87.0125	139.9814
422	1.3443	119.9846	77.3886	119.9647	1.8706	129.8287	86.8857	129.9124	1.3563	139.1488	87.0125	139.9814
423	1.3443	119.9846	77.3886	119.9647	1.8706	129.8287	86.8464	129.9124	1.3392	139.1086	86.9154	139.9814
424	1.3443	119.9846	77.3886	119.9647	1.8618	129.8287	86.8464	129.9124	1.3392	139.1086	86.9154	139.9292
425	1.3421	119.9846	77.3613	119.9647	1.8618	129.8287	86.8464	129.9124	1.3392	139.1086	86.9154	139.9292
426	1.3421	119.9846	77.3613	119.9647	1.8618	129.8287	86.8464	129.9124	1.3392	139.1364	86.9154	139.9292
427	1.3421	119.9846	77.3613	119.9547	1.8618	129.8287	86.8464	129.9124	1.3417	139.0930	87.0831	139.9292
428	1.4258	119.9846	77.3613	119.9847	1.8618	129.8287	86.8464	129.9124	1.3417	139.0930	87.0831	139.9292
429	1.4258	119.9846	77.4490	119.9847	1.8618	129.8287	86.8464	129.9124	1.3417	139.0930	87.0831	139.9292
430	1.4258	119.9846	77.4490	119.9847	1.8618	129.8287	86.8464	129.9124	1.3417	139.0530	87.0831	139.9292

Time	P	PC	HS	PS	P	PC	HS	PS	P	PC	HS	PS
431	1.4258	119.9846	77.4490	119.9847	1.8618	129.8287	87.0881	129.9124	1.3351	139.0787	87.0905	139.9292
432	1.9587	119.9846	77.4490	119.9847	1.8156	129.8287	87.0881	129.9124	1.3351	139.0787	87.0905	139.9292
433	1.9587	119.9846	77.7101	119.9847	1.8156	129.8287	87.0881	129.9124	1.3351	139.0787	87.0905	139.9292
434	1.9587	119.9846	77.7101	119.9847	1.8156	129.8287	87.0881	129.9124	1.3351	139.0791	87.0905	139.9292
435	7.4686	119.9846	77.7101	119.9847	1.8156	129.8287	87.0881	129.9124	1.3351	139.0893	87.0410	139.9292
436	7.4686	119.9846	77.7101	119.9847	1.8376	129.8287	87.0881	129.8124	1.3351	139.0893	87.0410	139.9292
437	7.4686	119.9846	77.9297	119.9847	1.8376	129.8287	87.0881	129.8124	1.3351	139.0893	87.0410	139.9292
438	7.4686	119.9846	77.9297	119.9847	1.8376	129.8287	87.0881	129.8124	1.3351	139.0705	87.0410	139.9292
439	13.9938	119.9846	77.9297	119.9847	1.8376	129.8287	87.0978	129.8124	1.3351	139.0453	87.0703	139.9292
440	13.9938	119.9846	77.9297	119.9847	1.8112	129.8287	87.0978	129.8124	1.3351	139.0453	87.0703	139.9292
441	13.9938	119.9846	78.2526	119.9847	1.8112	129.8287	87.0978	129.8124	1.3351	139.0453	87.0703	139.9292
442	13.9938	119.9846	78.2526	119.9847	1.8112	129.8287	87.3166	129.8124	1.3351	139.0680	87.0703	139.9292
443	20.4551	119.9846	78.2526	119.9847	1.8112	129.8287	87.3166	129.8124	1.3351	139.0400	86.9409	139.9292
444	20.4551	119.9846	78.2526	119.9847	1.7891	129.8287	87.3166	129.8124	1.3351	139.0400	86.9409	139.9292
445	20.4551	119.9846	78.2674	119.9847	1.7891	129.8287	87.5062	129.8124	1.3351	139.0400	86.9409	139.9292
446	20.4551	119.9846	78.2674	118.6705	1.7891	129.8287	87.5062	129.8124	1.3351	138.9869	86.9409	139.9292
447	26.8636	119.9846	78.2674	118.6705	1.7891	129.8287	87.5062	129.8124	1.3351	138.9514	86.9620	139.9292
448	26.8636	119.9846	78.2674	118.6705	1.7671	129.8287	87.5062	129.8124	1.3351	138.9514	86.9620	139.9292
449	26.8636	119.9846	78.1781	118.5928	1.7671	129.8287	87.2991	129.8124	1.3351	138.9514	86.9620	139.9292
450	26.8636	119.9846	78.1781	118.6137	1.7671	129.8287	87.2991	129.8001	1.3351	138.9376	86.9620	138.2301
451	33.1839	119.5717	78.1781	118.6137	1.7671	129.8287	87.2991	129.8001	1.4899	138.9258	87.0234	138.2301
452	33.1839	119.5717	78.1781	118.6137	1.7385	129.8287	87.2991	129.8001	1.4899	138.9258	87.0234	138.2301
453	33.1839	119.5717	78.3123	118.6137	1.7385	129.8287	87.2113	129.8001	1.4899	138.9258	87.0234	138.2301
454	39.5505	118.8168	78.3123	118.4938	1.7385	129.8287	87.2113	129.8001	1.4899	138.8923	87.0234	138.2301
455	39.5505	118.7318	78.3123	118.4938	1.7209	129.8287	87.2113	129.8001	1.4723	138.9084	86.9356	138.2301
456	39.5505	118.7318	78.3123	118.4938	1.7209	129.8287	87.1369	129.8001	1.4723	138.9084	86.9356	138.2301
457	45.7938	118.0945	79.0770	118.4938	1.7209	129.8287	87.1369	129.8001	1.4723	138.9084	86.9356	138.2301

Time	P	PC	HS	PS	P	PC	HS	PS	P	PC	HS	PS
458	45.7938	118.0945	79.0770	118.3274	1.7209	129.8287	87.1369	129.8001	1.4723	138.8569	86.9356	138.2301
459	45.7938	117.9327	79.0770	118.3274	1.7649	129.8287	87.1369	129.8001	1.3677	138.8486	86.9791	138.2301
460	45.7938	117.9327	79.0770	118.3274	1.7649	129.8287	86.8931	129.7124	1.3677	138.8486	86.9791	136.1148
461	51.6936	117.4267	81.6742	118.3274	1.7649	129.8287	86.8931	129.7124	1.3677	138.8486	86.9791	136.1148
462	51.6936	117.4267	81.6742	117.0812	1.7649	129.8287	86.8931	129.7124	1.3677	138.8348	86.9791	136.1148
463	51.6936	116.8652	81.6742	117.0812	1.9213	129.8287	86.8931	129.7124	1.5670	138.8588	87.0451	136.1148
464	51.6936	116.8652	81.6742	117.0812	1.9213	129.8287	86.8931	129.7124	1.5670	138.8588	87.0451	136.1148
465	57.6109	116.2105	88.7071	117.0812	1.9213	129.8287	86.8931	129.7124	1.5670	138.8588	87.0451	136.1148
466	57.6109	116.2105	88.7071	116.0462	1.9213	129.8287	86.8931	129.7124	1.5670	138.8329	87.0451	136.1148
467	57.6109	115.4407	88.7071	116.0462	1.8486	129.8287	86.8931	128.7124	1.5010	138.8140	87.7422	136.1148
468	62.9271	114.9209	88.7071	116.0462	1.8486	129.8287	86.8931	128.7124	1.5010	138.8140	87.7422	134.0234
469	62.9271	114.9209	92.7560	116.0462	1.8486	129.8287	86.8931	128.7124	1.5010	138.8140	87.7422	134.0234
470	62.9271	114.9209	92.7560	114.7443	1.8486	129.8287	86.8551	128.7124	1.5010	138.7930	87.7422	134.0234
471	62.9271	113.9193	92.7560	114.7443	6.5327	129.8287	86.8551	128.7124	5.1632	138.7567	91.5099	131.9333
472	68.5537	113.4241	92.7560	114.7443	6.5327	129.8287	86.8551	128.7124	5.1632	138.7567	91.5099	131.9333
473	68.5537	113.4241	94.4969	114.7443	6.5327	129.8287	86.8551	127.8422	5.1632	138.7567	91.5099	131.9333
474	68.5537	113.4241	94.4969	113.1140	6.5327	129.8287	86.8551	127.8722	5.1632	138.7292	91.5099	131.9333
475	73.5352	112.2370	94.4969	113.1140	15.0047	129.8287	86.8551	127.9022	12.0738	138.4498	99.1583	129.7449
476	73.5352	112.2370	94.4969	113.1140	15.0047	129.8287	86.8551	127.9322	12.0738	138.4498	99.1583	129.7449
477	73.5352	112.2370	95.6030	113.1140	15.0047	129.8287	86.8551	127.9622	12.0738	138.4498	99.1583	129.7449
478	78.0915	111.8180	95.6030	111.3962	15.0047	129.8287	86.8551	127.1622	12.0738	138.1036	99.1583	129.7449
479	78.0915	111.0643	95.6030	111.3962	23.4303	129.8287	86.8551	125.6374	18.9535	137.5543	103.2324	127.8250
480	78.0915	111.0643	95.6030	111.3962	23.4303	129.8287	92.9616	125.6374	18.9535	137.5543	103.2324	127.8250
481	82.2119	110.6870	96.1556	111.3962	23.4303	129.8287	92.9616	123.9848	18.9535	137.5543	103.2324	127.8250
482	82.2119	110.6870	96.1556	109.9386	23.4303	129.8287	92.9616	123.9848	18.9535	136.8846	103.2324	127.8250
483	82.2119	109.9191	96.1556	109.9386	31.7085	129.8287	92.9616	123.9848	25.9541	136.0912	104.9939	125.9028
484	82.2119	109.9191	96.1556	109.9386	31.7085	129.8287	92.9616	122.5775	25.9541	136.0912	104.9939	125.9028

Time	P	PC	HS	PS	P	PC	HS	PS	P	PC	HS	PS
485	85.8500	109.6562	96.8996	109.9386	31.7085	129.8287	92.9616	122.5775	25.9541	136.0912	104.9939	125.9028
486	85.8500	109.6562	96.8996	108.4596	31.7085	129.8287	92.9616	122.5775	25.9541	135.3121	104.9939	125.9028
487	85.8500	108.8858	96.8996	108.4596	39.9558	129.8287	92.9616	122.5775	32.8096	134.7563	106.8623	124.3061
488	89.2546	108.6982	96.8996	108.4596	39.9558	129.8287	99.3409	121.4381	32.8096	134.7563	106.8623	124.3061
489	89.2546	108.6982	97.8568	108.4596	39.9558	129.8287	99.3409	121.4381	32.8096	134.7563	106.8623	124.3061
490	89.2546	108.6982	97.8568	106.7681	39.9558	129.8287	99.3409	121.4381	32.8096	134.1170	106.8623	124.3061
491	89.2546	108.1778	97.8568	106.7681	47.9564	129.8287	99.3409	121.4381	39.2180	133.5025	108.0383	122.8712
492	92.5601	107.9759	97.8568	106.7681	47.9564	128.4763	102.4994	120.1744	39.2180	133.5025	108.0383	122.8712
493	92.5601	107.9759	98.5001	106.7681	47.9564	128.4763	102.4994	120.1744	39.2180	133.5025	108.0383	122.8712
494	92.5601	107.9759	98.5001	105.2022	47.9564	128.4763	102.4994	120.1744	39.2180	132.8328	108.0383	122.8712
495	92.5601	107.3675	98.5001	105.2022	55.4285	128.4763	102.4994	120.1744	45.8929	132.2317	108.7759	121.5775
496	94.8812	107.1447	98.5001	105.2022	55.4285	126.9362	104.3924	119.1559	45.8929	132.2317	108.7759	121.5775
497	94.8812	107.1447	98.8816	105.2022	55.4285	126.9362	104.3924	119.1559	45.8929	132.2317	108.7759	121.5775
498	94.8812	107.1447	98.8816	103.7542	55.4285	126.9362	104.3924	119.1559	45.8929	131.5061	108.7759	121.5775
499	94.8812	106.6756	98.8816	103.7542	62.5307	126.9362	105.9194	119.1559	52.2199	130.9707	108.8758	120.3913
500	97.1341	106.5436	98.8816	103.7542	62.5307	125.3275	105.9194	118.1260	52.2199	130.9707	108.8758	120.3913
501	97.1341	106.5436	98.9644	103.7542	62.5307	125.3275	105.9194	118.1260	52.2199	130.9707	108.8758	120.3913
502	97.1341	106.5436	98.9644	102.5281	62.5307	125.3275	105.9194	118.1260	52.2199	130.2551	108.8758	120.3913
503	97.1341	106.1219	98.9644	102.5281	68.6573	125.3275	106.9698	118.1260	58.2738	129.7665	108.7882	119.3193
504	99.0522	106.0976	98.9644	102.5281	68.6573	123.8392	106.9698	117.2126	58.2738	129.7665	108.7882	119.3193
505	99.0522	106.0976	98.8920	102.5281	68.6573	123.8392	106.9698	117.2126	58.2738	129.7665	108.7882	119.3193
506	99.0522	106.0976	98.8920	101.4992	68.6573	123.8392	106.9698	117.2126	58.2738	129.0706	108.7882	119.3193
507	99.0522	105.7868	98.8920	101.4992	74.6099	123.8392	107.6930	117.2126	64.1295	128.6276	108.6416	118.2432
508	100.4176	105.7465	98.8920	101.4992	74.6099	122.3936	107.6930	116.3944	64.1295	128.6276	108.6416	118.2432
509	100.4176	105.7465	98.5978	101.4992	74.6099	122.3936	107.6930	116.3944	64.1295	128.6276	108.6416	118.2432
510	100.4176	105.7465	98.5978	100.7364	74.6099	122.3936	107.6930	116.3944	64.1295	127.9294	108.6416	117.5936
511	100.4176	105.3465	98.5978	100.7364	79.9106	122.3936	108.4241	116.3944	69.6328	127.4442	108.4762	117.5936

Time	P	PC	HS	PS	P	PC	HS	PS	P	PC	HS	PS
512	101.4174	105.2129	98.5978	100.7364	79.9106	121.3838	108.4241	115.6689	69.6328	127.4442	108.4762	117.5936
513	101.4174	105.2129	98.1484	100.7364	79.9106	121.3838	108.4241	115.6689	69.6328	127.4442	108.4762	117.5936
514	101.4174	105.2129	98.1484	99.8350	79.9106	121.3838	108.4853	115.6689	69.6328	126.8382	108.4762	116.8132
515	101.4174	104.8902	98.1484	99.8350	84.5705	121.3838	108.4853	115.6689	74.6319	126.4482	108.2858	116.8132
516	101.7301	104.8222	98.1484	99.8350	84.5705	120.2738	108.4853	114.9519	74.6319	126.4482	108.2858	116.8132
517	101.7301	104.8222	97.6933	99.8350	84.5705	120.2738	108.5400	114.9519	74.6319	126.4482	108.2858	116.8132
518	101.7301	104.8222	97.6933	99.2070	84.5705	120.2738	108.5400	114.9519	74.6319	125.9058	108.2858	116.2336
519	101.7301	104.5565	97.6933	99.2070	88.5389	120.2738	108.5400	114.9519	79.2565	125.4687	107.7262	116.2336
520	101.9085	104.5391	97.6933	99.2070	88.5389	119.2901	108.3119	114.4688	79.2565	125.4687	107.7262	116.2336
521	101.9085	104.5391	97.2382	99.2070	88.5389	119.2901	108.3119	114.4688	79.2565	125.4687	107.7262	116.2336
522	101.9085	104.5391	97.2382	98.7611	91.6748	119.2901	108.3119	114.4688	79.2565	125.0177	107.7262	115.8266
523	101.9085	104.2491	97.2382	98.7611	91.6748	119.2901	108.0085	114.4688	83.3042	124.7680	107.7209	115.8266
524	101.9988	104.1498	97.2382	98.7611	91.6748	118.4660	108.0085	114.0976	83.3042	124.7680	107.7209	115.8266
525	101.9988	104.1498	96.7199	98.7611	91.6748	118.4660	108.0085	114.0976	83.3042	124.7680	107.7209	115.3166
526	101.9988	104.1498	96.7199	98.1285	94.5333	118.4660	107.9013	114.0976	83.3042	124.3387	107.7209	115.3166
527	101.9988	103.8680	96.7199	98.1285	94.5333	118.4660	107.9013	114.0976	86.8454	124.0067	107.7698	115.3166
528	102.0362	103.8596	96.7199	98.1285	94.5333	117.5876	107.9013	113.7444	86.8454	124.0067	107.7698	115.3166
529	102.0362	103.8596	96.3760	98.1285	98.5722	117.5876	107.9013	113.7444	86.8454	124.0067	107.7698	115.0266
530	102.0362	103.8596	96.3760	97.4352	98.5722	117.5876	107.9598	113.7444	86.8454	123.6285	107.7698	115.0266
531	102.2455	103.6019	96.3760	97.4352	98.5722	117.5876	107.9598	113.7444	90.0518	123.3035	107.8923	115.0266
532	102.2455	103.6019	96.3760	97.4352	99.9838	116.9136	107.9598	113.3897	90.0518	123.3035	107.8923	115.0266
533	102.2455	103.6019	96.2796	97.4352	99.9838	116.9136	107.7548	113.3897	90.0518	123.3035	107.8923	114.7133
534	102.2455	103.6019	96.2796	96.9404	99.9838	116.9136	107.7548	113.3897	90.0518	122.9844	107.8923	114.7133
535	102.1398	103.3928	96.2796	96.9404	100.9043	116.5802	107.7548	113.3897	92.8926	122.7255	107.8291	114.7133
536	102.1398	103.3928	96.2796	96.9404	100.9043	116.5802	107.7548	113.0719	92.8926	122.7255	107.8291	114.7133
537	102.1398	103.3928	96.2624	96.9404	100.9043	116.5802	107.9261	113.0719	92.8926	122.7255	107.8291	114.4049
538	102.2411	103.2882	96.2624	96.4806	100.9043	116.5802	107.9261	113.0719	92.8926	122.4816	107.8291	114.4049

Time	P	PC	HS	PS	P	PC	HS	PS	P	PC	HS	PS
539	102.2411	103.0124	96.2624	96.4806	101.4416	116.2586	107.9261	113.0719	95.2754	122.2545	107.4088	114.4049
540	102.2411	103.0124	96.2624	96.4806	101.4416	116.2586	107.9261	112.9136	95.2754	122.2545	107.4088	114.4049
541	102.2411	103.0124	96.1820	96.4806	101.4416	116.2586	107.9525	112.9136	95.2754	122.2545	107.4088	114.3327
542	102.1970	100.8294	96.1820	96.0848	101.6354	115.9825	107.9525	112.9136	95.2754	122.0636	107.4088	114.3327
543	102.1970	100.6920	96.1820	96.0848	101.6354	115.9825	107.9525	112.9136	97.1561	121.9264	106.8987	114.3327
544	102.1970	100.6920	96.1820	96.0848	101.6354	115.9825	107.9525	112.7164	97.1561	121.9264	106.8987	114.3327
545	102.1970	100.6920	96.0234	96.0848	101.6354	115.4977	107.7645	112.7164	97.1561	121.9264	106.8987	114.0132
546	102.1904	98.2364	96.0234	95.7322	101.6971	115.4977	107.7645	112.7164	98.7726	121.7789	106.9012	114.0132
547	102.1904	98.1078	96.0234	95.7322	101.6971	115.4977	107.7645	112.7164	98.7726	121.5675	106.9012	114.0132
548	102.1904	98.1078	96.0234	95.7322	101.6971	115.1287	107.7645	112.5014	98.7726	121.5675	106.9012	114.0132
549	102.1904	98.1078	96.1710	95.7322	101.6971	115.1287	107.4553	112.5014	98.7726	121.5675	106.9012	114.0525
550	101.9768	95.7252	96.1710	95.3639	101.7345	115.1287	107.4553	112.5014	99.9640	121.3598	107.0642	114.0525
551	101.9768	95.5117	96.1710	95.3639	101.7345	115.1287	107.4553	112.5014	99.9640	121.1738	107.0642	114.0525
552	101.9768	95.5117	96.1710	95.3639	101.7345	114.8904	107.4553	112.0295	99.9640	121.1738	107.0642	114.0525
553	101.9746	93.1006	95.7100	95.0466	101.7345	114.8904	106.5172	112.0295	99.9640	121.1738	107.0642	114.0484
554	101.9746	93.1006	95.7100	95.0466	101.7213	114.8904	106.5172	112.0295	100.7171	121.1057	106.6713	114.0484
555	101.9746	92.9514	95.7100	95.0466	101.7213	114.5010	106.5172	112.0295	100.7171	120.9566	106.6713	114.0484
556	102.1089	90.5877	95.7100	95.0466	101.7213	114.5010	106.5172	111.4864	100.7171	120.9566	106.6713	114.0484
557	102.1089	90.5877	95.4693	94.8018	101.7213	114.5010	105.0985	111.4864	100.7171	120.9566	106.6713	113.8187
558	102.1089	90.5877	95.4693	94.8018	101.7323	114.5010	105.0985	111.4864	101.3337	120.8473	105.5625	113.8187
559	102.0847	88.6311	95.4693	94.8018	101.7323	114.1333	105.0985	111.4864	101.3337	120.7047	105.5625	113.8187
560	102.0847	88.6311	95.4693	94.8018	101.7323	114.1333	105.0985	111.3036	101.3337	120.7047	105.5625	113.8187
561	102.0847	88.6311	79.3379	94.5717	101.7323	114.1333	103.7817	111.3036	101.3337	120.7047	105.5625	113.4000
562	102.0847	88.6311	79.3379	94.5717	101.6993	114.1333	103.7817	111.3036	101.6553	120.5608	105.1982	113.4000
563	102.0913	84.9344	79.3379	94.5717	101.6993	113.7314	103.7817	111.3036	101.6553	120.1102	105.1982	113.4000
564	102.0913	84.9344	79.3379	94.5717	101.6993	113.7314	103.7817	109.5985	101.6553	120.1102	105.1982	113.4000
565	102.0913	84.9344	69.8641	94.5007	101.6993	113.7314	102.4880	109.5985	101.6553	120.1102	105.1982	107.9352

Time	P	PC	HS	PS	P	PC	HS	PS	P	PC	HS	PS
566	102.0693	82.8587	69.8641	94.5007	101.6729	113.7314	102.4880	109.5985	101.7632	120.0440	104.9984	107.9352
567	102.0693	80.6552	69.8641	94.5007	101.6729	113.3855	102.4880	109.5985	101.7632	117.2258	104.9984	107.9352
568	102.0693	80.6552	69.8641	94.5007	101.6729	113.3855	102.4880	103.4177	101.7632	117.2258	104.9984	107.9352
569	102.0693	80.6552	62.9646	94.4420	101.6729	113.3855	101.7301	103.4177	101.7632	117.2258	104.9984	103.4159
570	102.0869	78.9428	62.9646	94.4420	101.6883	113.3855	101.7301	103.4177	101.7037	117.0717	105.1070	103.4159
571	102.0869	77.0068	62.9646	94.4420	101.6883	113.2162	101.7301	103.4177	101.7037	113.6716	105.1070	103.4159
572	102.0869	77.0068	62.9646	94.4420	101.6883	113.2162	101.7301	97.9171	101.7037	113.6716	105.1070	103.4159
573	102.0495	75.5243	57.9676	94.1299	101.6883	113.2162	101.2168	97.9171	101.7037	113.6716	105.1070	98.7713
574	102.0495	75.5243	57.9676	94.1299	101.7566	113.2162	101.2168	97.9171	101.7081	113.6213	105.0395	98.7713
575	102.0495	73.4514	57.9676	94.1299	101.7566	111.9532	101.2168	97.9171	101.7081	110.2685	105.0395	98.7713
576	102.0495	73.4514	57.9676	94.1299	101.7566	111.9532	89.0945	92.4476	101.7081	110.2685	105.0395	98.7713
577	102.0407	72.0164	54.8699	93.2557	101.7566	111.9532	89.0945	92.4476	101.7081	110.2685	105.0395	93.9124
578	102.0407	72.0164	54.8699	90.3353	101.8425	111.7979	89.0945	92.4476	101.7147	110.1905	104.6183	93.9124
579	102.0407	69.9096	54.8699	90.3353	101.8425	111.7979	74.1265	92.4476	101.7147	107.6815	104.6183	93.9124
580	102.0407	69.9096	54.8699	90.3353	101.8425	111.7979	74.1265	86.7985	101.7147	107.6815	104.6183	93.9124
581	102.0517	68.5710	51.2095	90.3353	101.8425	111.7979	74.1265	86.7985	101.7147	107.6815	104.6183	88.5308
582	102.0517	68.5710	51.2095	85.8927	101.8226	111.7134	64.9316	86.7985	101.7235	107.6477	104.1767	88.5308
583	102.0517	66.7076	51.2095	85.8927	101.8226	111.7134	64.9316	86.7985	101.7235	105.0434	104.1767	88.5308
584	102.0517	66.7076	51.2095	85.8927	101.8226	111.7134	64.9316	82.1884	101.7235	105.0434	104.1767	88.5308
585	102.0296	65.4258	47.9220	85.8927	101.8094	111.5912	64.9316	82.1884	101.7235	105.0434	104.1767	85.0392
586	102.0296	65.4258	47.9220	81.6383	101.8094	111.5912	58.0939	82.1884	101.8689	105.0537	104.3936	85.0392
587	102.0296	65.1516	47.9220	81.6383	101.8094	111.5912	58.0939	82.1884	101.8689	102.4496	104.3936	85.0392
588	102.0296	65.1516	47.9220	81.6383	101.8094	111.5912	58.0939	78.5272	101.8689	102.4496	104.3936	85.0392
589	102.0208	64.0749	44.2325	81.6383	101.6024	109.4001	58.0939	78.5272	101.8689	102.4496	104.3936	81.3336
590	102.0208	64.0749	44.2325	74.4199	101.6024	109.4001	53.1190	78.5272	101.7522	98.6987	100.3730	81.3336
591	102.0208	64.2372	44.2325	74.4199	101.6024	109.4001	53.1190	78.5272	101.7522	98.6987	100.3730	81.3336
592	102.0208	64.2372	44.2325	74.4199	101.8579	109.4001	53.1190	74.8305	101.7522	98.6987	100.3730	81.3336

Time	P	PC	HS	PS	P	PC	HS	PS	P	PC	HS	PS
593	102.0054	63.2875	41.8800	74.4199	101.8579	102.0854	53.1190	74.8305	101.7522	98.6987	100.3730	75.9020
594	102.0054	63.2875	41.8800	69.3919	101.8579	102.0854	53.3555	74.8305	101.7125	95.3831	83.1784	75.9020
595	102.0054	60.4902	41.8800	69.3919	101.8579	102.0854	53.3555	74.8305	101.7125	95.3831	83.1784	75.9020
596	102.0054	60.4902	41.8800	69.3919	101.8182	102.0854	53.3555	71.2257	101.7125	95.3831	83.1784	75.9020
597	102.0054	59.6068	39.5650	69.3919	101.8182	95.8108	51.7866	71.2257	101.7125	95.3831	83.1784	71.9626
598	102.0054	59.6068	39.5650	63.8284	101.8182	95.8108	51.7866	71.2257	101.7323	87.8555	73.2880	71.9626
599	102.0054	57.5307	39.5650	63.8284	101.8182	95.8108	51.7866	71.2257	101.7323	87.8555	73.2880	71.9626
600	102.0230	56.7289	39.5650	63.8284	101.7940	90.8715	49.2753	68.0871	101.7323	87.8555	73.2880	71.9626
601	102.0230	56.7289	37.7138	63.8284	101.7940	90.8715	49.2753	68.0871	101.7323	87.8555	73.2880	68.2835
602	102.0230	56.7289	37.7138	60.3265	101.7940	90.8715	49.2753	68.0871	101.7059	78.7442	65.3480	68.2835
603	102.0230	54.8383	37.7138	60.3265	101.7940	85.4561	46.4211	68.0871	101.7059	78.7442	65.3480	68.2835
604	102.0274	54.1008	37.7138	60.3265	101.7874	85.4561	46.4211	65.1705	101.7059	78.7442	65.3480	68.2835
605	102.0274	54.1008	36.0495	60.3265	101.7874	85.4561	46.4211	65.1705	101.7059	78.7442	65.3480	64.5822
606	102.0274	54.1008	36.0495	55.9323	101.7874	79.7942	46.4211	65.1705	101.6883	74.4364	58.5657	64.5822
607	102.0098	51.6164	36.0495	55.9323	101.7610	79.7942	44.4473	65.1705	101.6883	74.4364	58.5657	64.5822
608	102.0098	51.6164	36.0495	55.9323	101.7610	79.7942	44.4473	61.7342	101.6883	74.4364	58.5657	64.5822
609	102.0098	51.6164	34.8721	55.9323	101.7610	79.7942	44.4473	61.7342	101.6883	74.4364	58.5657	60.9113
610	102.0098	51.6164	34.8721	53.6202	101.7522	74.9517	44.4473	61.7342	101.7103	70.6922	53.0793	60.9113
611	101.9988	49.3681	34.8721	53.6202	101.7522	74.9517	43.9779	61.7342	101.7103	70.6922	53.0793	60.9113
612	101.9988	49.3681	34.8721	53.6202	101.7522	74.9517	43.9779	58.0937	101.7103	70.6922	53.0793	60.9113
613	101.9988	49.3681	33.6335	53.6202	101.7389	74.9517	43.9779	58.0937	101.7103	70.6922	53.0793	57.7142
614	101.9966	48.7907	33.6335	51.3391	101.7389	70.8412	43.9779	58.0937	101.7037	67.0499	50.5859	57.7142
615	101.9966	47.2610	33.6335	51.3391	101.7389	70.8412	44.6036	58.0937	101.7037	67.0499	50.5859	57.7142
616	101.9966	47.2610	33.6335	51.3391	101.7389	70.8412	44.6036	55.1432	101.7037	67.0499	50.5859	57.7142
617	101.9966	47.2610	32.7437	51.3391	101.7610	70.8412	44.6036	55.1432	101.7037	67.0499	50.5859	52.2196
618	101.9988	46.6687	32.7437	48.6951	101.7610	67.0905	44.6036	55.1432	101.6927	61.3356	46.8249	52.2196
619	101.9988	45.3190	32.7437	48.6951	101.7610	67.0905	42.9917	55.1432	101.6927	61.3356	46.8249	52.2196

Time	P	PC	HS	PS	P	PC	HS	PS	P	PC	HS	PS
620	101.9988	45.3190	32.7437	48.6951	101.7610	67.0905	42.9917	52.4548	101.6927	61.3356	46.8249	52.2196
621	101.9724	44.7931	31.0395	45.4888	101.7103	67.0905	42.9917	52.4548	101.6927	61.3356	46.8249	49.4144
622	101.9724	44.7931	31.0395	45.4888	101.7103	63.9109	42.9917	52.4548	101.6729	60.4289	41.9483	49.4144
623	101.9724	43.6544	31.0395	45.4888	101.7103	63.9109	40.9789	52.4548	101.6729	60.4289	41.9483	49.4144
624	101.9724	43.6544	31.0395	45.4888	101.7103	63.9109	40.9789	50.0135	101.6729	60.4289	41.9483	49.4144
625	101.9614	43.1861	28.5807	42.7363	101.7169	63.9109	40.9789	50.0135	101.6729	60.4289	41.9483	47.2384
626	101.9614	43.1861	28.5807	42.7363	101.7169	61.1261	40.9789	50.0135	101.6641	54.3358	39.7652	47.2384
627	101.9614	42.1602	28.5807	42.7363	101.7169	61.1261	39.4001	50.0135	101.6641	54.3358	39.7652	47.2384
628	101.9812	41.7415	28.5807	42.7363	101.7169	61.1261	39.4001	47.7544	101.6641	54.3358	39.7652	47.2384
629	101.9812	41.7415	28.1108	40.6596	101.7015	61.1261	39.4001	47.7544	101.6641	52.6210	39.7652	45.1367
630	101.9812	41.7415	28.1108	40.6596	101.7015	57.8291	39.4001	47.7544	101.6487	52.6210	36.9034	45.1367
631	101.9812	40.7743	28.1108	40.6596	101.7015	57.8291	36.6290	47.7544	101.6487	52.6210	36.9034	45.1367
632	101.9460	40.3695	28.1108	40.6596	101.7015	57.8291	36.6290	45.8146	101.6487	52.6210	36.9034	45.1367
633	101.9460	40.3695	29.1332	35.2264	101.6971	57.8291	36.6290	45.8146	101.6487	50.2425	36.9034	42.5792
634	101.9460	40.3695	29.1332	35.2264	101.6971	55.6946	34.6231	45.8146	101.6509	50.2425	33.2676	42.5792
635	101.9460	39.4212	29.1332	35.2264	101.6971	55.6946	34.6231	45.8146	101.6509	50.2425	33.2676	42.5792
636	101.9460	39.0728	29.1332	35.2264	101.6971	55.6946	34.6231	43.8942	101.6509	50.2425	33.2676	42.5792
637	101.9460	39.0728	28.9598	32.9672	101.6839	55.6946	34.6231	43.8942	101.6509	47.7162	33.2676	40.0428
638	101.9460	39.0728	28.9598	32.9672	101.6839	51.9200	32.9239	43.8942	101.6509	47.7162	30.3878	40.0428
639	101.9460	38.2668	28.9598	32.9672	101.6839	51.9200	32.9239	43.8942	101.6509	47.7162	30.3878	40.0428
640	101.9283	37.9556	28.9598	32.9672	101.6839	51.9200	32.9239	42.1998	101.6509	47.7162	30.3878	40.0428
641	101.9283	37.9556	28.3241	31.0947	101.6663	51.9200	32.9239	42.1998	101.6509	23.1575	30.3878	37.9900
642	101.9283	37.9556	28.3241	31.0947	101.6663	48.5306	32.2985	42.1998	101.6575	23.1575	28.5873	37.9900
643	101.9349	36.9904	28.3241	31.0947	101.6663	48.5306	32.2985	42.1998	101.6575	23.1575	28.5873	37.9900
644	101.9349	36.9904	28.3241	31.0947	101.6663	48.5306	32.2985	40.6292	101.6575	23.1575	28.5873	37.9900
645	101.9349	36.9904	27.8839	30.0765	101.6487	48.5306	30.3352	40.6292	101.6575	20.5585	28.5873	36.1481
646	101.9349	36.9904	27.8839	30.0765	101.6487	44.8574	30.3352	40.6292	101.6729	20.5585	27.8079	36.1481

Time	P	PC	HS	PS	P	PC	HS	PS	P	PC	HS	PS
647	101.9548	35.9855	27.8839	30.0765	101.6487	44.8574	30.3352	40.6292	101.6729	20.5585	27.8079	36.1481
648	101.9548	35.9855	27.8839	30.0765	101.6487	44.8574	30.3352	39.2086	101.6729	20.5585	27.8079	36.1481
649	101.9548	35.9855	27.5930	28.8250	101.6376	41.8850	28.7017	39.2086	101.6729	20.3561	27.8079	34.4225
650	101.9548	35.4374	27.5930	28.8250	101.6376	41.8850	28.7017	39.2086	101.6376	20.3561	27.8237	33.2236
651	101.7213	35.1798	27.5930	28.8250	101.6376	41.8850	28.7017	39.2086	101.6376	20.3561	27.8237	33.2236
652	101.7213	35.1798	27.5930	28.8250	101.6376	41.8850	28.7416	38.0048	101.6376	20.3561	27.8237	33.2236
653	101.7213	35.1798	27.4962	27.8898	101.6443	39.6770	28.7416	38.0048	101.6376	20.2999	27.8237	33.2236
654	101.7213	34.5639	27.4962	27.8898	101.6443	39.6770	28.7416	38.0048	101.6244	20.2999	27.1555	32.0747
655	101.7235	34.3039	27.4962	27.8898	101.6443	39.6770	28.7416	38.0048	101.6244	20.2999	27.1555	32.0747
656	101.7235	34.3039	27.4962	27.8898	101.6310	37.8863	29.0725	36.7480	101.6244	20.2885	27.1555	32.0747
657	101.7235	34.3039	29.2104	27.0486	101.6310	37.8863	29.0725	36.7480	101.6244	20.2885	27.1555	32.0747
658	101.7235	33.8470	29.2104	27.0486	101.6310	37.8863	29.0725	36.7480	101.6310	20.2885	27.6383	31.1339
659	101.8865	33.6046	29.2104	27.0486	101.6310	37.8863	29.0496	36.7480	101.6310	20.2885	27.6383	31.1339
660	101.8865	33.6046	29.2104	27.0486	101.6178	36.3415	29.0496	35.6567	101.6310	20.3662	27.6383	31.1339
661	101.8865	33.6046	29.7613	26.7362	101.6178	36.3415	29.0496	35.6567	101.6310	20.3662	27.6383	31.1339
662	101.9526	32.8596	29.7613	26.7362	101.6178	36.3415	29.0496	35.6567	101.6398	20.3662	28.0814	30.4310
663	101.9526	32.8596	29.7613	26.7362	101.6156	34.9415	29.0865	35.6567	101.6398	20.3662	28.0814	30.4310
664	101.9526	32.8596	29.7613	26.7362	101.6156	34.9415	29.0865	34.6284	101.6398	20.4699	28.0814	30.4310
665	101.9526	32.8596	28.8050	26.2063	101.6156	34.9415	29.0865	34.6284	101.6398	20.4699	28.0814	30.4310
666	101.9482	32.2099	28.8050	26.2063	101.6156	34.9415	28.5228	34.6284	101.6465	20.4699	30.6912	29.5540
667	101.9482	32.2099	28.8050	26.2063	101.6112	33.7438	28.5228	34.6284	101.6465	20.4699	30.6912	29.5540
668	101.9482	32.2099	28.8050	26.2063	101.6112	33.7438	28.5228	33.6941	101.6465	20.4015	30.6912	29.5540
669	101.8579	32.0049	28.8705	25.6521	101.6112	33.7438	28.5228	33.6941	101.6465	20.4015	30.6912	29.5540
670	101.8579	31.5028	28.8705	25.6521	101.6134	32.8590	28.8896	33.6941	101.6244	20.4015	30.6548	28.9551
671	101.8579	31.5028	28.8705	25.6521	101.6134	32.8590	28.8896	33.6941	101.6244	20.4015	30.6548	28.9551
672	101.8579	31.5028	28.8705	25.6521	101.6134	32.8590	28.8896	32.9865	101.6244	20.3625	30.6548	28.9551
673	101.8160	31.3653	27.1510	24.7639	101.6134	32.8590	29.5247	32.9865	101.6244	20.3625	30.6548	28.9551

Time	P	PC	HS	PS	P	PC	HS	PS	P	PC	HS	PS
674	101.8160	30.9506	27.1510	24.7639	101.5936	31.8790	29.5247	32.9865	101.6222	20.3625	29.9384	28.4429
675	101.8160	30.9506	27.1510	24.7639	101.5936	31.8790	29.5247	32.9865	101.6222	20.3625	29.9384	28.4429
676	101.9460	30.7848	27.1510	24.7639	101.5936	31.8790	29.5247	32.3144	101.6222	20.4634	29.9384	28.4429
677	101.9460	30.7848	26.5992	24.1384	101.6002	31.8790	28.9490	32.3144	101.6222	20.4634	29.9384	28.4429
678	101.9460	30.3839	26.5992	24.1384	101.6002	31.1279	28.9490	32.3144	101.6156	20.4634	30.8867	27.8940
679	101.9460	30.3839	26.5992	24.1384	101.6002	31.1279	28.9490	32.3144	101.6156	20.4634	30.8867	27.8940
680	101.9570	30.2555	26.5992	24.1384	101.6002	31.1279	28.9490	31.4355	101.6156	20.4906	30.8867	27.8940
681	101.9570	30.2555	26.7367	23.5032	101.5980	31.1279	28.0234	31.4355	101.6156	20.4906	30.8867	27.8940
682	101.9570	29.7820	26.7367	23.5032	101.5980	30.2208	28.0234	31.4355	101.6310	20.4906	30.5832	27.5149
683	101.9460	29.6376	26.7367	23.5032	101.5980	30.2208	28.0234	31.4355	101.6310	20.4906	30.5832	27.5149
684	101.9460	29.6376	26.7367	23.5032	101.5980	30.2208	28.0234	30.7439	101.6310	20.3521	30.5832	27.5149
685	101.9460	29.6376	27.0838	22.6585	101.5936	29.6208	28.0580	30.7439	101.6310	20.3521	30.5832	27.5149
686	101.9460	29.3215	27.0838	22.6585	101.5936	29.6208	28.0580	30.7439	101.6024	20.3521	29.6116	27.6712
687	101.7279	29.2066	27.0838	22.6585	101.5936	29.6208	28.0580	30.7439	101.6024	20.3521	29.6116	27.6712
688	101.7279	29.2066	27.0838	22.6585	101.5936	29.6208	28.0580	30.1357	101.6024	20.7186	29.6116	27.6712
689	101.7279	29.2066	25.0804	22.0067	101.6068	28.7107	28.7611	30.1357	101.6024	20.7186	29.6116	27.6712
690	101.7367	28.7051	25.0804	22.0067	101.6068	28.7107	28.7611	30.1357	101.6200	20.7186	28.9713	27.2732
691	101.7367	28.7051	25.0804	22.0067	101.6068	28.7107	28.7611	30.1357	101.6200	-	28.9713	27.2732
692	101.7367	28.7051	25.0804	22.0067	101.5826	28.7107	28.7611	29.6349	101.6200	-	28.9713	27.2732
693	101.7301	28.6092	25.3796	21.5338	101.5826	28.0862	28.6206	29.6349	101.6200	-	28.9713	27.2732
694	101.7301	28.3136	25.3796	21.5338	101.5826	28.0862	28.6206	29.6349	101.6222	-	28.4965	27.1972
695	101.7301	28.3136	25.3796	21.5338	101.5826	28.0862	28.6206	29.6349	101.6222	-	28.4965	27.1972
696	101.7301	28.3136	25.3796	21.5338	101.5870	27.5074	28.6206	29.1936	101.6222	-	28.4965	27.1972
697	101.7103	28.1827	25.2246	21.3202	101.5870	27.5074	28.5522	29.1936	101.6222	-	28.4965	27.1972
698	101.7103	27.9288	25.2246	21.3202	101.5870	27.5074	28.5522	29.1936	101.6090	-	28.2142	26.8137
699	101.7103	27.9288	25.2246	21.3202	101.5870	27.5074	28.5522	29.1936	101.6090	-	28.2142	26.8137
700	101.7103	27.9288	25.2246	21.3202	101.5804	27.0817	28.5522	28.8534	101.6090	-	28.2142	26.8137

P = Pressure, PC = Product center, HS = vessel headspace, PS = Product surface.

Table A.2. Temperatures profiles during traditional frying at 165°C.

Time [s]	PC [°C]	PS [°C]
1	22.1771	20.6888
2	22.1771	20.6888
3	22.1771	20.6888
4	22.1771	20.6888
5	22.9734	20.5599
6	22.9734	20.5599
7	22.9734	20.5599
8	22.9734	20.5599
9	22.9066	20.3924
10	22.9066	20.3924
11	22.9066	20.3924
12	22.9066	20.3924
13	22.7148	20.0418
14	22.7148	20.0418
15	22.7148	20.0418
16	22.7148	20.0418
17	22.6345	19.9664
18	22.6345	19.9664
19	22.6345	19.9664
20	22.6345	19.9664
21	27.6292	20.0497
22	27.6292	20.0497
23	27.6292	20.0497
24	27.6292	20.0497
25	67.0938	73.453
26	67.0938	73.453
27	67.0938	73.453
28	67.0938	73.453
29	99.5447	82.4125
30	99.5447	82.4125
31	99.5447	82.4125
32	99.5447	82.4125
33	107.8462	104.2943
34	107.8462	104.2943
35	107.8462	104.2943
36	107.8462	104.2943
37	105.8038	108.2636
38	105.8038	108.2636
39	105.8038	108.2636
40	105.8038	108.2636
41	105.9106	109.7108

Time	PC	PS
42	105.9106	109.7108
43	105.9106	109.7108
44	105.9106	109.7108
45	104.4546	111.7418
46	104.4546	111.7418
47	104.4546	111.7418
48	104.4546	111.7418
49	104.4286	114.0925
50	104.4286	114.0925
51	104.4286	114.0925
52	104.4286	114.0925
53	104.1225	115.8609
54	104.1225	115.8609
55	104.1225	115.8609
56	104.1225	115.8609
57	104.0112	117.5888
58	104.0112	117.5888
59	104.0112	117.5888
60	104.0112	117.5888
61	103.2681	119.6256
62	103.2681	119.6256
63	103.2681	119.6256
64	103.2681	119.6256
65	103.2803	120.7486
66	103.2803	120.7486
67	103.2803	120.7486
68	103.2803	120.7486
69	103.3446	123.628
70	103.3446	123.628
71	103.3446	123.628
72	103.3446	123.628
73	103.9206	126.1605
74	103.9206	126.1605
75	103.9206	126.1605
76	103.9206	126.1605
77	103.4483	128.3991
78	103.4483	128.3991
79	103.4483	128.3991
80	103.4483	128.3991
81	103.3801	129.5191
82	103.3801	129.5191
83	103.3801	129.5191
84	103.3801	129.5191
85	104.31	129.9644

Time	PC	PS
86	104.31	129.9644
87	104.31	129.9644
88	104.31	129.9644
89	105.4142	130.9352
90	105.4142	130.9352
91	105.4142	130.9352
92	105.4142	130.9352
93	106.4752	131.8145
94	106.4752	131.8145
95	106.4752	131.8145
96	106.4752	131.8145
97	106.2664	133.6306
98	106.2664	133.6306
99	106.2664	133.6306
100	106.2664	133.6306
101	108.084	133.5589
102	108.084	133.5589
103	108.084	134.5589
104	108.084	134.5589
105	110.6842	135.2977
106	110.6842	135.2977
107	110.6842	135.2977
108	110.6842	135.2977
109	115.7506	135.569
110	115.7506	135.569
111	115.7506	135.569
112	115.7506	135.569
113	119.8064	137.4125
114	119.8064	137.4125
115	119.8064	137.4125
116	119.8064	137.4125
117	126.9286	139.3619
118	126.9286	139.3619
119	126.9286	139.3619
120	126.9286	139.3619
121	131.6093	141.3722
122	131.6093	141.3722
123	131.6093	141.3722
124	131.6093	141.3722
125	139.3766	144.0981
126	139.3766	144.0981
127	139.3766	144.0981
128	139.3766	144.0981
129	143.2462	147

Time	PC	PS
130	143.2462	147
131	143.2462	147
132	143.2462	147
133	145.0506	151.3817
134	145.0506	151.3817
135	145.0506	151.3817
136	145.0506	151.3817
137	147.2268	151.1944
138	147.2268	151.1944
139	147.2268	151.1944
140	149.2268	151.1944
141	149.6323	153.6511
142	149.6323	153.6511
143	149.6323	153.6511
144	149.6323	153.6511
145	151.6546	154.6505
146	151.6546	154.6505
147	151.6546	154.6505
148	151.6546	154.6505
149	152.2913	155.517
150	154.2913	155.517
151	154.2913	155.517
152	154.2913	155.517
153	154.6749	156.9801
154	154.6749	156.9801
155	154.6749	156.9801
156	154.6749	156.9801
157	156.9149	157.3842
158	156.9149	157.3842
159	156.9149	157.3842
160	156.9149	157.3842
161	157.3865	157.4997
162	157.3865	157.4997
163	157.3865	157.4997
164	157.3865	157.4997
165	157.4219	158.2291
166	157.4219	158.2291
167	157.4219	158.2291
168	157.4219	158.2291
169	157.5108	157.7219
170	157.5108	157.7219
171	157.5108	157.7219
172	158.5108	157.7219
173	158.0782	159.39

Time	PC	PS
174	158.0782	159.39
175	158.0782	159.39
176	158.0782	159.39
177	158.3687	160.1692
178	158.3687	160.1692
179	158.3687	160.1692
180	158.3687	160.1692
181	159.2009	161.5985
182	159.7009	161.5985
183	159.7009	161.5985
184	159.7009	161.5985
185	160.0966	161.6067
186	160.0966	161.6067
187	160.0966	161.6067
188	160.0966	161.6067
189	160.2783	162.8656
190	160.2783	162.8656
191	160.2783	162.8656
192	160.2783	162.8656
193	160.1498	162.7057
194	160.1498	162.7057
195	160.1498	162.7057
196	160.1498	163.2057
197	160.2589	162.5682
198	160.2589	162.5682
199	160.2589	162.5682
200	160.2589	162.5682
201	160.2238	162.9887
202	160.2238	162.9887
203	160.2238	162.9887
204	160.2238	162.9887
205	160.2873	163.0088
206	160.2873	163.0088
207	160.2873	163.0088
208	160.2873	163.0088
209	160.2476	162.8851
210	160.2476	162.8851
211	160.2476	162.8851
212	160.2476	162.8851
213	160.1426	162.955
214	160.1426	162.955
215	160.1426	162.955
216	160.1426	162.955
217	160.7498	162.815

Time	PC	PS
218	160.7498	162.815
219	160.7498	162.815
220	160.7498	162.815
221	160.7452	162.2602
222	160.7452	162.2602
223	160.7452	162.2602
224	160.7452	162.2602
225	160.7835	162.7337
226	160.7835	162.7337
227	160.7835	162.7337
228	160.7835	162.7337
229	160.7687	162.7411
230	160.7687	162.7411
231	160.7687	162.7411
232	160.7687	162.7411
233	160.6786	162.7923
234	160.6786	162.7923
235	161.1786	162.7923
236	161.1786	162.7923
237	162.5937	162.7523
238	162.5937	162.7523
239	162.5937	162.7523
240	162.5937	162.7523
241	163.6733	163.3523
242	163.6733	163.3523
243	163.6733	163.3523
244	163.6733	163.3523
245	163.5055	163.3523
246	163.5055	163.3523
247	163.5055	163.3523
248	163.5055	163.3523
249	163.4085	163.7976
250	163.4085	163.7976
251	163.4085	163.7976
252	163.1085	163.7976
253	163.1085	164.379
254	163.1085	164.379
255	163.1085	164.379
256	162.5794	164.379
257	162.5794	164.01
258	162.5794	164.01
259	162.5794	164.01
260	162.8207	164.01
261	162.8207	164.4296

Time	PC	PS
262	162.8207	164.4296
263	162.8207	164.4296
264	162.9502	164.4296
265	162.9502	164.4887
266	162.9502	164.4887
267	162.9502	164.4887
268	163.3012	164.4887
269	163.3012	164.4438
270	163.3012	164.4438
271	163.3012	164.4438
272	163.3698	164.4438
273	163.3698	164.3764
274	163.3698	164.3764
275	163.3698	164.3764
276	163.5645	164.3764
277	163.5645	164.1476
278	163.5645	164.1476
279	163.5645	164.1476
280	163.8235	164.1476
281	163.8235	164.2455
282	163.8235	164.2455
283	163.8235	164.2455
284	163.8409	164.2455
285	163.8409	164.1884
286	163.8409	164.1884
287	163.8409	164.1884
288	163.7833	164.1884
289	163.7833	163.8557
290	163.7833	163.8557
291	163.7833	163.8557
292	163.7038	163.8557
293	163.7038	164.6049
294	164.1038	164.6049
295	164.1038	164.6049
296	164.0074	164.6049
297	164.0074	164.2876
298	164.0074	164.2876
299	164.0074	164.2876
300	163.7913	164.2876
301	163.7913	164.139
302	163.7913	164.139
303	164.1913	164.139
304	164.0585	164.139
305	164.0585	164.4491

Time	PC	PS
306	164.0585	164.4491
307	164.0585	164.4491
308	164.0859	164.4491
309	164.0859	162.7469
310	164.0859	162.7469
311	164.0859	162.7469
312	163.7592	162.7469
313	164.5592	164.6959
314	164.5592	164.6959
315	164.5592	164.6959
316	164.5285	164.6959
317	164.5285	164.3666
318	164.5285	164.3666
319	164.5285	164.3666
320	164.4858	164.3666
321	164.4858	164.4568
322	164.4858	164.4568
323	164.4858	164.4568
324	164.2417	164.4568
325	164.2417	164.8779
326	164.2417	164.8779
327	164.2417	164.8779
328	164.0237	164.8779
329	164.0237	164.5157
330	164.0237	164.5157
331	164.0237	164.5157
332	164.0373	164.5157
333	164.0373	164.7221
334	164.0373	164.7221
335	164.0373	164.7221
336	164.0494	164.7221
337	164.0494	164.2645
338	164.0494	164.2645
339	164.0494	164.2645
340	164.0043	164.5645
341	164.0043	164.4524
342	164.0043	164.4524
343	164.0043	164.4524
344	164.2457	164.4524
345	164.2457	164.0341
346	164.2457	164.0341
347	164.2457	164.0341
348	163.7758	164.0341
349	163.7758	164.7191

Time	PC	PS
350	163.7758	164.7191
351	163.7758	164.7191
352	163.5547	164.7191
353	163.5547	164.444
354	163.5547	164.444
355	163.5547	164.444
356	163.6115	164.444
357	163.6115	164.6006
358	163.6115	164.6006
359	163.6115	164.6006
360	163.7304	164.6006
361	163.7304	164.8583
362	163.7304	164.8583
363	163.7304	164.8583
364	163.5835	164.8583
365	163.5835	164.8964
366	163.5835	164.8964
367	163.5835	164.8964
368	163.4014	164.8964
369	163.4014	163.985
370	163.1014	163.985
371	163.1014	163.985
372	163.0146	163.985
373	163.0146	163.2898
374	163.0146	163.2898
375	163.0146	163.2898
376	148.559	163.2898
377	148.559	151.4365
378	148.559	151.4365
379	148.559	151.4365
380	133.6645	151.4365
381	133.6645	125.8071
382	133.6645	125.8071
383	133.6645	125.8071
384	121.2908	125.8071
385	121.2908	111.2299
386	121.2908	111.2299
387	121.2908	111.2299
388	111.5955	111.2299
389	111.5955	101.4467
390	111.5955	101.4467
391	111.5955	101.4467
392	103.7584	101.4467
393	103.7584	92.8062

Time	PC	PS
394	103.7584	92.8062
395	103.7584	92.8062
396	96.5569	92.8062
397	96.5569	84.2954
398	96.5569	84.2954
399	96.5569	84.2954
400	90.1488	77.1641
401	90.1488	77.1641
402	90.1488	77.1641
403	90.1488	77.1641
404	84.3476	71.3188
405	84.3476	64.8289
406	84.3476	64.8289
407	84.3476	64.8289
408	79.3339	64.8289
409	79.3339	60.3675
410	79.3339	60.3675
411	79.3339	60.3675
412	74.9521	60.3675
413	74.9521	56.4566
414	74.9521	56.4566
415	74.9521	56.4566
416	70.9028	56.4566
417	70.9028	52.9126
418	70.9028	52.9126
419	70.9028	49.8737
420	67.199	49.8737
421	67.199	49.8737
422	67.199	47.162
423	67.199	47.162
424	63.8207	47.162
425	63.8207	47.162
426	63.8207	44.6233
427	63.8207	44.6233
428	60.6317	44.6233
429	60.6317	44.6233
430	60.6317	42.3082
431	60.6317	42.3082
432	57.7478	42.3082
433	57.7478	42.3082
434	57.7478	40.3553
435	57.7478	40.3553
436	55.2034	40.3553
437	55.2034	40.3553

Time	PC	PS
438	55.2034	38.5254
439	55.2034	38.5254
440	52.792	38.5254
441	52.792	38.5254
442	52.792	36.9883
443	52.792	36.9883
444	50.7332	36.9883
445	50.7332	36.9883
446	50.7332	35.5531
447	50.7332	35.5531
448	49.1356	35.5531
449	49.1356	35.5531
450	49.1356	34.4055
451	49.1356	34.4055
452	47.316	34.4055
453	47.316	34.4055
454	47.316	33.2537
455	47.316	33.2537
456	45.7349	33.2537
457	45.7349	33.2537
458	45.7349	32.2022
459	45.7349	32.2022
460	43.8001	32.2022
461	43.8001	32.2022
462	43.8001	31.1705
463	43.8001	31.1705
464	41.9764	31.1705
465	41.9764	31.1705
466	41.9764	30.2289
467	41.9764	30.2289
468	40.3768	30.2289
469	40.3768	30.2289
470	40.3768	29.5325
471	40.3768	29.5325
472	38.7578	29.5325
473	38.7578	29.5325
474	38.7578	28.742
475	38.7578	28.742
476	37.2946	28.742
477	37.2946	28.742
478	37.2946	28.052
479	37.2946	28.052
480	36.105	28.052
481	36.105	28.052

Time	PC	PS
482	36.105	27.4271
483	36.105	27.4271
484	35.0199	27.4271
485	35.0199	27.4271
486	35.0199	26.9208
487	35.0199	26.9208
488	33.9779	26.9208
489	33.9779	26.9208
490	33.9779	26.4829
491	33.9779	26.4829
492	33.1246	26.4829
493	33.1246	26.4829
494	33.1246	26.0691
495	33.1246	26.0691
496	32.4359	26.0691
497	32.4359	26.0691
498	32.4359	25.6768
499	32.4359	25.6768
500	31.6764	25.6768
501	31.6764	25.6768
502	31.6764	25.3137
503	31.6764	25.3137
504	31.1593	25.3137
505	31.1593	25.3137
506	31.1593	25.0631
507	31.1593	25.0631
508	30.6073	25.0631
509	30.6073	25.0631
510	30.6073	24.7845
511	30.6073	24.7845
512	29.9286	24.7845
513	29.9286	24.7845
514	29.9286	24.532
515	29.9286	24.532
516	29.2219	24.532
517	29.2219	24.532
518	29.2219	24.2516
519	29.2219	24.2516
520	28.597	24.2516
521	28.597	24.2516
522	28.597	24.0456
523	28.597	24.0456
524	28.0843	24.0456
525	28.0843	24.0456

Time	PC	PS
526	28.0843	23.8606
527	28.0843	23.8606
528	27.4862	23.8606
529	27.4862	23.8606
530	27.4862	23.5562
531	27.4862	23.5562
532	26.9666	23.5562
533	26.9666	23.5562
534	26.9666	23.4429
535	26.9666	23.4429
536	26.4911	23.4429
537	26.4911	23.4429
538	26.4911	23.2664
539	26.4911	23.2664
540	26.0909	23.2664
541	26.0909	23.2664
542	26.0909	23.1371
543	26.0909	23.1371
544	25.7623	23.1371
545	25.7623	23.1371
546	25.7623	22.9753
547	25.7623	22.9753
548	25.4105	22.9753
549	25.4105	22.9753
550	25.4105	22.849

PC = Product center, PS = Product surface.

Table A.3. Effect of frying time and oil temperature on moisture and oil content of potato chips fried under vacuum.

T_{oil} [°C]	Time [s]	MC [g/g solid]	St. Dev. [g/g solid]	IOC [g/g solid]	St. Dev. [g/g solid]	TOC [g/g solid]	St. Dev. [g/g solid]	SOC [g/g solid]
120	0	2.6114	0.0325	-	-	-	-	-
120	20	1.5900	0.0204	0.0624	0.0020	0.0757	0.0048	0.0133
120	40	1.0018	0.0171	0.0950	0.0037	0.1687	0.0070	0.0737
120	60	0.8244	0.0061	0.1069	0.0033	0.2732	0.0036	0.1664
120	80	0.4207	0.0097	0.1159	0.0025	0.3036	0.0046	0.1877
120	100	0.2078	0.0029	-	-	-	-	-
120	120	0.1023	0.0028	0.1199	0.0019	0.3561	0.0024	0.2362
120	180	0.0363	0.0018	0.1050	0.0014	0.3812	0.0063	0.2762
120	240	0.0222	0.0050	0.0929	0.0044	0.4006	0.0099	0.3077
120	300	0.0196	0.0031	0.0758	0.0022	0.4054	0.0079	0.3296
120	360	0.0154	0.0002	0.0715	0.0038	0.4102	0.0050	0.3387
130	0	2.6114	0.0325	-	-	-	-	-
130	20	1.2619	0.0183	0.0861	0.0033	0.1024	0.0056	0.0163
130	40	0.7351	0.0050	0.1010	0.0031	0.1979	0.0099	0.0969
130	60	0.3118	0.0055	0.1146	0.0018	0.2616	0.0080	0.1470
130	80	0.1021	0.0018	0.1246	0.0031	0.3547	0.0073	0.2301
130	100	0.0302	0.0016	-	-	-	-	-
130	120	0.0257	0.0030	0.1182	0.0045	0.4765	0.0061	0.3583
130	180	0.0150	0.0006	0.0909	0.0023	0.5102	0.0033	0.4194
130	240	0.0138	0.0015	0.0723	0.0027	0.4802	0.0047	0.4079
130	300	0.0156	0.0043	0.0654	0.0017	0.4653	0.0087	0.3999
130	360	0.0159	0.0011	0.0620	0.0028	0.4753	0.0039	0.4134
140	0	2.6114	0.0325	-	-	-	-	-
140	20	1.1064	0.0138	0.0912	0.0029	0.1039	0.0028	0.0126
140	40	0.7717	0.0100	0.1229	0.0042	0.2136	0.0057	0.0907
140	60	0.2822	0.0056	0.1277	0.0037	0.2607	0.0045	0.1329
140	80	0.0830	0.0003	0.1137	0.0050	0.3760	0.0048	0.2623
140	100	0.0295	0.0004	-	-	-	-	-
140	120	0.0225	0.0003	0.0985	0.0036	0.4747	0.0095	0.3763
140	180	0.0149	0.0004	0.0802	0.0023	0.5178	0.0057	0.4376
140	240	0.0147	0.0001	0.0751	0.0030	0.4796	0.0069	0.4045
140	300	0.0145	0.0004	0.0629	0.0020	0.4545	0.0082	0.3916
140	360	0.0146	0.0004	0.0590	0.0031	0.4568	0.0075	0.3979

T_{oil} = Temperature of the oil; MC = Moisture content, IOC = Internal oil content, TOC = Total oil content, SOC = Surface oil content, St. Dev. = Standard deviation.

Table A.4. Effect of frying time and oil temperature on true density, bulk density, and porosity of potato chips fried under vacuum.

T_{oil} [°C]	Time [s]	ρ_b [kg/m3]	St. Dev. [kg/m3]	ρ_t [kg/m3]	St. Dev. [kg/m3]	ϕ [-]	St. Dev. [-]
120	0	1102.747	21.471	1087.981	3.023	-	-
120	20	1106.206	33.322	1124.531	8.893	0.016296	0.0848
120	40	1109.104	16.537	1168.839	5.487	0.051106	0.0870
120	60	888.136	41.672	1189.128	6.947	0.25312	0.0836
120	80	786.785	35.552	1253.356	6.233	0.372258	0.0846
120	120	580.161	18.421	1352.905	4.081	0.571174	0.0824
120	180	444.947	19.823	1392.734	5.324	0.680522	0.0863
120	240	432.968	7.689	1390.978	5.680	0.688732	0.0899
120	300	455.123	12.404	1398.323	4.252	0.674522	0.0879
120	360	452.222	10.506	1408.029	4.565	0.678826	0.0850
130	0	1102.747	21.471	1087.981	3.023	-	-
130	20	1084.685	26.989	1149.017	3.018	0.055988	0.0856
130	40	925.610	10.020	1201.920	4.471	0.229891	0.0899
130	60	814.206	30.749	1283.250	0.491	0.365512	0.0880
130	80	503.117	27.699	1353.942	9.426	0.628406	0.0873
130	120	462.433	30.891	1394.512	3.839	0.689903	0.0861
130	180	447.380	19.950	1402.316	2.741	0.688101	0.0833
130	240	440.169	13.634	1407.027	3.251	0.6829	0.0847
130	300	459.909	5.445	1406.433	7.842	0.687799	0.0887
130	360	457.594	6.954	1399.637	3.023	0.679374	0.0839
140	0	1102.747	21.471	1087.981	3.023	-	-
140	20	1078.752	26.841	1161.617	8.882	0.071336	0.0828
140	40	922.941	18.163	1197.239	4.471	0.329109	0.0857
140	60	620.320	28.572	1289.804	0.491	0.519059	0.0845
140	80	478.307	21.652	1369.553	9.426	0.650757	0.0848
140	120	446.582	13.229	1396.218	5.324	0.687149	0.0895
140	180	446.315	18.910	1402.351	3.839	0.688738	0.0857
140	240	454.629	8.328	1406.529	2.137	0.686772	0.0869
140	300	468.666	11.349	1398.851	8.629	0.688964	0.0882
140	360	450.841	13.725	1403.955	3.023	0.678878	0.0875

T_{oil} = Temperature of oil, ρ_b = Bulk density, ρ_t = True density, ϕ = Porosity.

Table A.5. Effect of frying time and oil temperature on diameter and thickness of potato chips fried under vacuum.

T_{oil} [°C]	Time [s]	S [%]	St. Dev. [%]	L [%]	St. Dev. [%]
120	20	8.591	0.663	-28.472	1.418
120	40	10.103	0.671	-30.139	1.049
120	60	9.849	0.828	-28.750	1.443
120	80	8.451	0.531	-19.514	1.256
120	120	7.023	0.487	-6.667	0.955
120	180	9.388	0.525	-3.681	1.536
120	240	9.587	0.623	-0.972	1.684
120	300	8.764	0.826	1.042	1.267
120	360	8.926	0.402	3.264	1.049
130	20	9.221	0.805	-32.458	0.908
130	40	8.541	0.522	-26.472	0.789
130	60	6.420	0.627	-18.889	0.985
130	80	7.979	0.735	-14.583	1.458
130	120	9.974	0.273	-4.653	0.842
130	180	9.895	0.710	-1.389	1.478
130	240	9.057	0.457	-0.139	1.147
130	300	9.116	0.618	2.778	1.203
130	360	9.525	0.389	3.681	0.867
140	20	9.136	0.568	-34.444	0.939
140	40	5.407	0.591	-24.444	1.185
140	60	8.007	0.655	-9.306	1.147
140	80	8.434	0.176	-4.236	0.434
140	120	8.314	0.557	-1.806	0.939
140	180	8.952	0.662	1.319	1.478
140	240	8.655	0.461	1.250	1.573
140	300	8.438	0.717	2.312	1.147
140	360	8.451	0.330	3.194	1.069

T_{oil} = Temperature of oil, S = Diameter shrinkage, L = Thickness expansion,
St. Dev. = Standard deviation.

Table A.6. Effect of frying time and moisture content on heat capacity of potato chips fried under vacuum at 120°C.

Time	MC	Cp	St. Dev.
[s]	[g/g product]	[J/kgK]	[J/kgK]
0	0.7231	3369.424	6.056
20	0.6139	3235.424	12.613
40	0.5004	3046.064	6.265
60	0.4519	2591.773	11.066
80	0.2961	2509.924	8.552
120	0.0928	2001.424	9.505
180	0.0350	1842.924	13.025
240	0.0217	1827.424	9.736
300	0.0193	1771.924	10.862
360	0.0152	1763.818	8.3198

MC = Moisture content (w.b.), Cp = Heat capacity, St. Dev. = Standard deviation

Table A.7. Effect of frying time and oil temperature on convective heat transfer coefficient of potato chips fried under vacuum.

Toil [°C]	Time [s]	TS [°C]	dm/dt [kg/s]	A [m2]	h [W/m2K]
120	0	16.494	5.75E-05	2.03E-03	678.011
120	20	95.952	3.63E-05	1.69E-03	2204.839
120	40	96.239	2.29E-05	1.64E-03	1456.449
120	60	96.704	1.45E-05	1.65E-03	932.530
120	80	98.538	9.13E-06	1.70E-03	619.627
120	100	100.032	5.76E-06	1.73E-03	413.940
120	120	104.797	3.64E-06	1.75E-03	337.961
120	180	115.218	9.15E-07	1.66E-03	284.573
120	240	118.304	2.3E-07	1.66E-03	202.771
120	300	119.474	5.79E-08	1.69E-03	161.439
120	360	119.755	1.46E-08	1.68E-03	87.450
130	0	15.277	8.82E-05	2.03E-03	938.326
130	20	104.293	4.38E-05	1.67E-03	2523.328
130	40	108.391	2.17E-05	1.70E-03	1468.597
130	60	109.130	1.08E-05	1.77E-03	721.250
130	80	110.982	5.36E-06	1.72E-03	406.474
130	100	118.195	2.66E-06	1.68E-03	332.359
130	120	122.694	1.32E-06	1.64E-03	272.597
130	180	128.433	1.62E-07	1.65E-03	155.406
130	240	129.595	1.98E-08	1.68E-03	72.214
130	300	129.912	2.43E-09	1.67E-03	40.967
130	360	129.912	2.97E-10	1.66E-03	5.062
140	0	16.577	9.75E-05	2.03E-03	964.532
140	20	115.055	4.47E-05	1.67E-03	2649.683
140	40	118.632	2.05E-05	1.81E-03	1308.353
140	60	119.566	9.39E-06	1.72E-03	663.135
140	80	122.360	4.31E-06	1.70E-03	355.427
140	100	124.826	1.97E-06	1.70E-03	189.162
140	120	132.526	9.05E-07	1.70E-03	175.809
140	180	138.189	8.71E-08	1.68E-03	70.862
140	240	138.489	8.39E-09	1.69E-03	8.128
140	300	139.389	8.09E-10	1.70E-03	1.926
140	360	139.929	7.79E-11	1.70E-03	1.603

Toil = Temperature of oil, TS = Temperature at the surface of the chip, dm/dt = Drying rate, A = Surface area, h = convective heat transfer coefficient.

VITA

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