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Simiulation of moisture loss and oil absorbation during batch deep frying of egg plants

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ABSTRACT

Eggplant has a short shelf life due to its high moisture content and softening of the tissue during storage. Therefore, it is necessary to use appropriate methods for processing to increase storage time and maintain its nutritional value. In fact, understanding the heat and mass transfer during frying can be useful for optimizing and controlling the process as much as possible. In this study, the effect of frying at 160, 180, and 200 °C for 20, 36, 124, and 200 seconds on moisture content, oil content, moisture, and oil transfer kinetics and estimation of convective heat transfer coefficient was analyzed. The results showed that the samples fried at 160 °C for 124 seconds had the lowest oil absorption. It was also found that as the temperature and frying time decreased, the oil content of the samples also decreased. In addition, the experimental models fit the experimental data well. In addition, the results showed that the sample fried for 200 seconds at 200 °C had the lowest moisture content ratio. It is known increasing the frying temperature of the synthetic constant also increases the decrease in humidity, which indicates that the rate of moisture exit of the product was higher at high temperatures than at lower temperatures. Also, increasing the frying time and temperature reduced the moisture content of the samples. The convective heat transfer coefficient is higher in the early times of the process and decreases with time as the frying time elapses. The maximum value of h was related to the twentieth seconds at a frying temperature of 200 °C.

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1. Introduction

Eggplant is considered an economically important agricultural product in Asia and Europe. According to statistics published by the Food and Agriculture Organization of Iran, after China and India, it ranks third in the world with a production of 1.2 million tons per year [1]. Every 100 grams of eggplant contains approximately 86.13% water, 9.41% carbohydrates, 3% fiber, 0.98% protein, 0.18% fat, and 0.3% vitamins and minerals [2]. Eggplant is a significant component of Mediterranean cuisine, used in many traditional recipes, and serves as an important source of bioactive compounds, playing a crucial role in preventing chronic diseases [3]. Due to its high moisture content and softening of the texture over time during storage, eggplant has a short shelf life. Therefore, using appropriate methods for processing, extending storage time, and preserving its nutritional value is essential. One of the oldest cooking methods for food, including eggplant, is frying, which can be either shallow or deep. These methods are commonly used in the food industry due to their simplicity and relatively low costs [4,5]. Deep frying is a fast-cooking process, often chosen to create uniform aroma, flavor, color, and texture in processed foods [6]. The frying process is a simultaneous mass and heat transfer process [7], where heat is transferred by convection from the oil to the surface of the food, and through conduction from the surface to the inside of the food. As a result, moisture is evaporated from the food, and oil is absorbed into the product [8]. In deep frying, heat transfer is a combination of two methods: convection (heat transfer from oil to food) and conduction (heat transfer inside the food) [9]. The advantages of deep frying, in addition to forming desirable texture, color, aroma, and taste in the final product, include the high speed of heat transfer. This occurs due to the evaporation of moisture as steam during the frying process, leading to turbulence and an increase in the convection heat transfer coefficient [10]. However, some of the main disadvantages of deep frying include shrinkage or reduction in the apparent volume of the final product, the formation of a toxic and carcinogenic compound called acrylamide, which results from a reaction between reducing sugars and amino acids at high frying temperatures, and the high oil content in the fried food, which in some cases can reach up to one-third of the total weight of the product [11–13]. In other words, understanding phenomena such as structural changes that occur during deep frying of food in oil is important for controlling the quality of the final fried product and energy consumption during the frying process from an engineering and economic perspective. From the consumer's point of view, the health, appearance, and sensory properties of the final product are also very important [14,15]. Therefore, the main goal of a control system should be to maximize the preservation of nutrients and health while optimizing energy consumption. In fact, understanding heat and mass transfer during frying can be beneficial for optimizing and better controlling the process [14]. Shahin et al. (1999) studied the heat transfer coefficient during the frying of potatoes and found that these parameters increase with an increase in oil temperature. After the formation of a crust, the evaporation rate decreases, which leads to a reduction in the convection heat transfer coefficient. Also, as the steam bubbles rise to the upper surface of the oil, the heat transfer coefficient at the upper surface is lower than at the lower surface due to the insulating effect of the steam bubbles [16]. Sabaghian et al. (2014) examined the heat transfer coefficient as a function of the rate of moisture reduction during the frying process, considering the effects of moisture evaporation and boiling on this thermal parameter. They concluded that the heat transfer coefficient increases at higher temperatures due to the higher moisture evaporation rate, and at lower temperatures, the heat transfer coefficient decreases because of the lower convection heat transfer at lower oil temperatures [17]. Yildiz et al. (2007) estimated the heat transfer coefficient using the natural logarithmic equation for temperature and moisture without dimension versus time. They found that the heat transfer coefficient decreased with increasing oil temperature. The increased moisture evaporation rate at higher frying temperatures required more energy for evaporation, which resulted in a decrease in the available energy for internal energy increase and noticeable temperature changes in the food, thereby reducing the effective heat transfer coefficient [18]. Hamid Beigi and Nasser Hamdami (2013) studied the kinetics of oil absorption and moisture loss during the frying

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of potato slices. They found that increasing the frying temperature significantly increased oil absorption and moisture loss from the slices. Various kinetic models were investigated to describe oil absorption, moisture loss, and changes in the firmness of the crust and core of the fried slices. The results showed that the first-order kinetic model with product limitation provided the best fit to the experimental data for moisture loss and residual oil in the slices [19]. The objective of this research is to determine the effect of different oil frying temperatures and frying process time on moisture content and oil absorption of fried eggplant pieces under deep frying conditions, and to estimate the convection heat transfer coefficient with product surface temperature and the kinetics of mass and moisture transfer in eggplant.

2. Materials and Methods

1.2. Raw Materials

The eggplants used were purchased from the local market and stored in a refrigerator at 4°C until the experiments were conducted. The oil used was a liquid frying oil (a mixture of sunflower oil, cottonseed oil, and soybean oil) branded as "Oila". The solvent used for extracting oil from the fried samples was petroleum ether (Dr. Majali), manufactured in Iran.

2.2. Sample Preparation

For each experiment, the eggplants were washed, peeled, and then cut into rectangular cubes of 5 cm length, 3 cm width, and 1 cm height using a manual cutter (aluminum mold).

3.2. Frying Process and Temperature Recording

The frying process for the eggplant slices was carried out in a fryer (Suzuki - Model ZDF2510, Japan) containing 2 liters of oil, equipped with a temperature controller (thermocontroller) and a Type K thermocouple at 160, 180, and 200°C. To measure and record the temperature changes of the product during frying, three Type T thermocouples were placed in the center and surface of the product. The temperature of the T-type thermocouples was recorded at 2-second intervals using a data logger and transferred to a computer. This process continued from the beginning of frying until the product reached its final fried state. To determine moisture content and oil absorption during frying, samples were removed from the fryer at 20, 36, 124, and 200 seconds, and their surface oil was removed using absorbent paper. Immediately after that, the relevant analyses were performed. All experiments were carried out in triplicate.

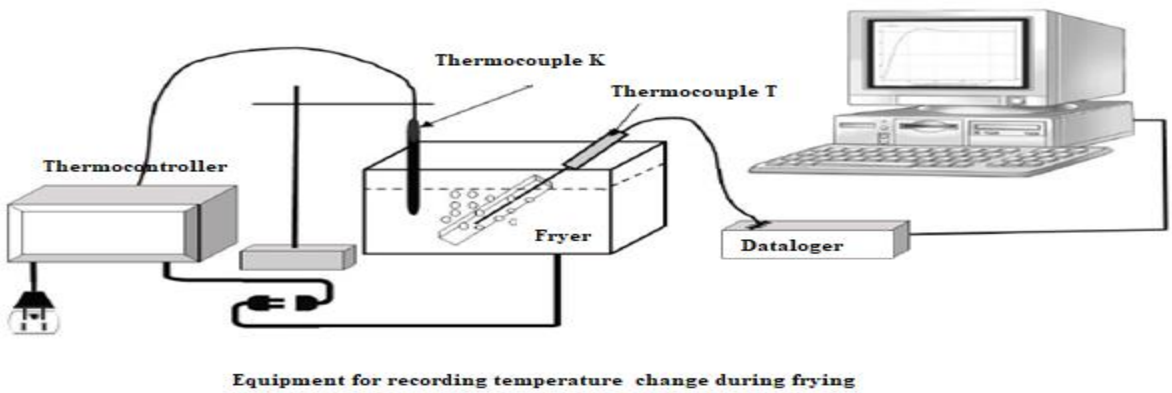

Figure 1. diagram of frying operation and recording ofthe temperature of eggplant slices during deep frying

4.2. Moisture Content

The moisture content of the fried eggplant samples before and after frying (after removing the oil) was determined by drying them in a convection oven (Memmert - Germany) at 105°C until a constant weight was achieved [20].

5.2. Oil Extraction

The oil content of the fried samples was measured by extracting the oil in a Soxhlet apparatus (Bahar - Germany) and determining it in terms of grams of oil per gram of dry matter using petroleum ether as a solvent [20].

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2.6. Estimation of the Convection Heat Transfer Coefficient with Product Surface Temperature

In this method, it is assumed that the total heat transferred (in J. s^{-1}) from the oil to the surface of the eggplant slices (qT) is used for heating the eggplant (qh) and for the evaporation of water (qe) [21]. The convection heat transfer coefficient will be estimated based on equations (1 and 2) in terms of W/m²°C:

$$q_h = \gamma q_T = \gamma A_p h\,(T_{st} - T_0) \quad \text{Eq.1}$$

$$q_e = (1-\gamma)\, qT = (1-\gamma)\, Aph\,(T_{st} - T_0) = \lambda \dot{W} \quad \text{Eq.2}$$

Ap = Surface area of the eggplant (m²), **T_0** and **Tst** are the initial and surface temperatures of the eggplant slices (°C) at time zero and time t in seconds, respectively. **qh** = Thermal energy used for heating the eggplant, **m** = Mass of the eggplant slices (kg), **Cp, ave** = Average specific heat capacity of the eggplant, **$\dot{W}$** = Rate of water loss from the product (kg.s^{-1}), **ɣ** = Fraction of **qT** used for heating the eggplant, **λ** = Latent heat of water evaporation in the eggplant.

The convection heat transfer coefficient can be estimated by obtaining the value of **ɣh** from equation (3) and adding it to the value of (1-ɣ) h derived from equation (4). For each time, the values of **Tsi** and **Tst** were experimentally determined and used in the equations.

$$y_h = mc_p, ave\,(T_{st} - T_{si}) / tA_p\,(T_{st} - T_0) \quad \text{Eq.3}$$

$$(1-\gamma)\, h = \lambda w / Ap\,(T_{si} - T_0) \quad \text{Eq.4}$$

Tsi and **Tst** are the surface temperatures of the eggplant slices (°C) at time **t** and at time zero, respectively.

2-7- Kinetics of Moisture and Oil Transfer

The changes in moisture content of the product during frying follow a decreasing exponential function. The moisture reduction kinetics during frying, as described by Krokida et al. (2001) and Baik and Mittal (2005), were considered in the form of an exponential function, as shown in equation (5) [22,23].

$$\mathrm{Ln}\,(m_t - m_e / m_i - m_e) = -Kmt \quad \text{Eq.5}$$

In the above equation, **mi** is the initial moisture content of the product (g/g, db), **mt** is the moisture content of the samples at any moment (g/g, db), and **me** is the equilibrium moisture content of the samples (the moisture content of the samples at infinite time).

The above kinetic model was evaluated based on experimental data by plotting **Ln(mt/m0)** versus time and obtaining the slope of the resulting line to estimate the kinetic constant **Km** for different experimental temperatures. The kinetic model for oil absorption was proposed in the form of equation (6), as suggested by Krokida et al. [8].

$$O = O_{eq}[1 - \exp(-k_0 t)] \quad \text{Eq.6}$$

In this equation, **O** represents the oil content of the product (g oil/g dry matter) at time **t**, **Oeq** is the equilibrium oil content or the maximum oil content in the dry matter at time **t = ∞**, **t** is the frying time, and **K_0** is the rate constant or specific kinetic constant for oil absorption (1/s). In this model, at time **t = 0**, the oil content of the product was considered zero, and after prolonged frying, the oil content was assumed to reach the equilibrium value **Oeq**.

3. Statistical Analysis

In this study, the data obtained from the experiments were statistically analyzed using a factorial design based on a completely randomized design with **Design Expert software (version 0.0.7)**. Duncan's multiple range test was used for mean comparison at a significance level of **$P \leq 0.05$**, and all graphs were plotted using **Microsoft Excel 2016**.

4. Results and Discussion

4-1. Investigation of Core and Surface Temperature Changes of Eggplant During Deep Frying

Figure 1 illustrates the changes in core and surface temperatures of the eggplant samples during deep frying at three different oil temperatures. As shown, the temperature profiles followed a two-stage pattern. In the present study, the rate of temperature increases for all treatments, both at the core and surface of the samples, continued up to the boiling point of water. Afterward, the temperature of the product remained nearly constant throughout the frying process.

At an oil temperature of 200°C, the core temperature of the product reached the vicinity of water's boiling point within approximately 50 seconds, whereas at 160°C and 180°C, this duration extended to nearly 90 seconds from the start of the process. Initially, due to the vapor pressure resulting from water evaporation and the entrapment of vapor bubbles inside the product caused by crust formation, the boiling

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point of water increased in accordance with thermodynamic principles. As the evaporation rate and boiling phase decreased over time, the boiling point gradually declined, and both the core and surface temperatures of the product remained slightly below 100°C until the end of frying.

Heat transfer during deep frying occurs through two thermal sinks. The first sink involves **sensible heat**, which raises the product's temperature from its initial value to near the boiling point of water. This sink is limited once the core temperature reaches the boiling point. The second sink corresponds to the **crust/core interface**, where water undergoes phase change into vapor and is maintained throughout the frying process [24].

With increasing frying temperatures, the duration of the constant temperature phase shortens in the temperature profile [25]. Sabbaghi et al. monitored the surface and core temperature changes of potato strips using thermocouples at oil temperatures of 145, 160, and 180°C for 175, 120, 60, and 180 seconds. They segmented the temperature evolution into time-dependent stages. Their results showed that the core temperature remained constant after reaching the boiling point of water for all three oil temperatures. For surface temperature, the initial heating stage was observed prior to vaporization at constant temperature. This stage was shortened as the core temperature approached boiling point—lasting about 60 seconds in their study, which is consistent with the present results [17].

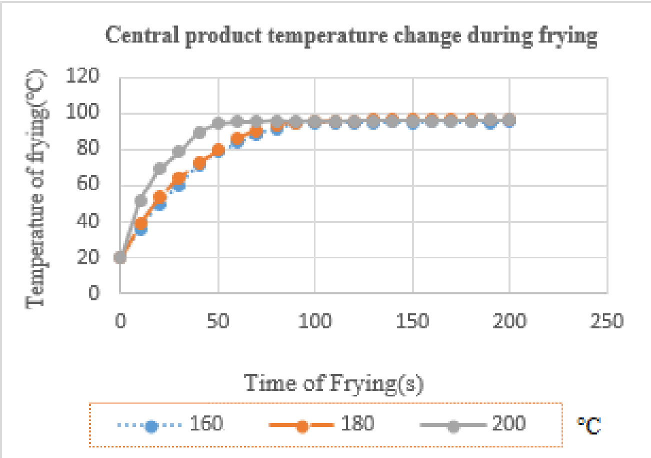

Figure 1. Comparison of central product temperature changes during eggplant frying at aco a constant oil temperature160, 180 and 200 °C

As shown in Figure 2, the surface temperature changes of the product followed a pattern similar to that of the core temperature, with the difference that the time required to reach the boiling point of water was shorter. This can be attributed to the direct contact between the oil and the surface of the product, which results in a higher heat transfer rate. At an oil temperature of 200°C, the surface temperature reached the boiling range of water in approximately 30 seconds, whereas at 160°C and 180°C, this occurred around 60 seconds after the start of the process.

The surface temperature of the product reached the boiling point of water sooner, and after the surface water evaporated and a crust formed, the temperature remained nearly constant until the end of frying. The completion of the frying process was determined based on moisture reduction and the achievement of the desired fried appearance and texture of the samples. The total frying durations at oil temperatures of 200°C, 180°C, and 160°C were 200, 260, and 320 seconds, respectively.

Based on the observed temperature trends in the above graphs and the non-significant difference between surface and core temperature changes, fixed frying times of 20, 36, 124, and 200 seconds were selected at the three oil temperatures (160°C, 180°C, and 200°C) for further investigation of the physical parameters related to the frying process of eggplant.

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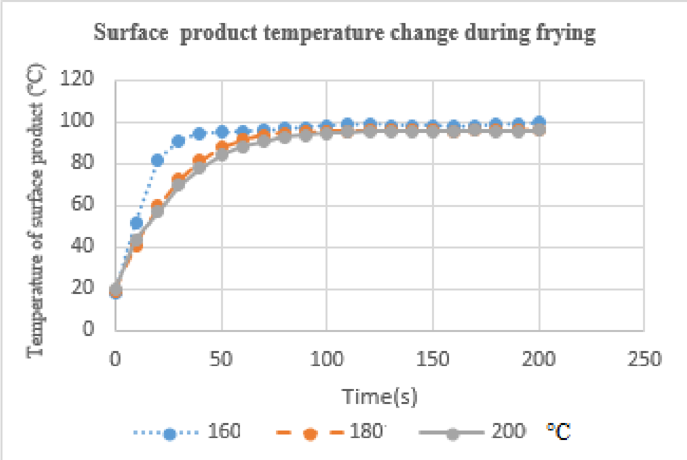

Figure 2. Comparison of product surface temperature changes at oil temperatures of 160, 180 and 200 °C during frying time

2-4. Evaluation of Moisture and Oil Content at Different Frying Temperatures and Times

In the analysis of moisture content, the independent effects of both temperature and time were statistically significant at the 95% confidence level. However, for the oil content of fried eggplant, only the independent effect of temperature was found to be significant at the same confidence level. Figures 3 and 4 illustrate the mean variations in moisture and oil content of the product during frying under different process temperatures and times. A comparison of these graphs reveals a relationship between moisture loss and oil absorption, influenced by frying temperature and process duration.

The moisture content of the product decreased at higher oil temperatures, and as frying time increased, the rate of moisture loss gradually diminished. The slope of the graphs at all three frying temperatures supports this observation. The high rate of evaporation within the first 20 seconds of frying at all temperatures is likely due to the sudden vaporization of free surface water. The vapor pressure difference between the product and the frying oil results in rapid water evaporation, which is most pronounced at the beginning of the frying process when the partial pressure difference is at its peak.

Sabaghi et al. studied the changes in moisture and mean oil content during frying of potato slices at various temperatures and times. Their results indicated that from the beginning of the process until 120 seconds, there was no significant difference between moisture and oil content, which could be explained by the high rate of evaporation during this period [17]. Romani et al. also observed that the rate of moisture reduction and oil uptake stabilized approximately three minutes after the start of the process. They reported a relatively rapid and significant increase in oil absorption during the initial 120 seconds, which was attributed to the replacement of evaporated water by oil [24]. Farkas et al. stated that as long as the core temperature of the product remains around 100°C, the rate of oil migration into the product remains negligible. Moisture reduction leads to the formation of pores, which in turn facilitates oil absorption [25]. Sabaghi et al. also demonstrated during deep-fat frying of potato slices at three different temperatures that once the central temperature reached 100°C (around 60 seconds into the process), the rate of oil penetration decreased compared to the early stages, which aligns with the findings of this study [17].

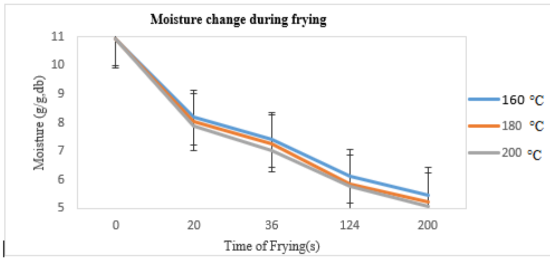

Figure 3. Moisture changes of eggplant pieces during frying

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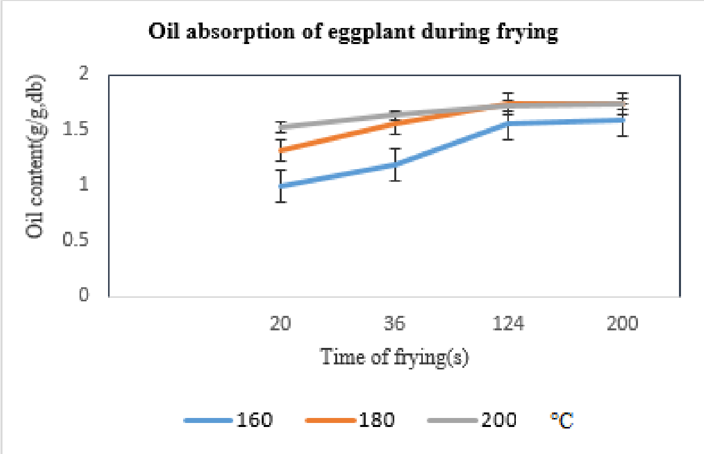

Figure 4. Changes in oil absorption of eggplant pieces during frying at three different temperatures

According to Figure 4, the highest oil uptake occurred in the 200-second treatment at oil temperatures of 200°C and 180°C. The rate of oil absorption was more intense during the initial seconds of the process, especially at lower temperatures. Once the core temperature of the product reached approximately 100°C, the rate of oil migration into the product became negligible. Romani et al. (2008) reported that oil absorption exhibits a relatively rapid and significant increase during the first 120 seconds of the process, which can be attributed to the replacement of evaporated water by oil [24]. In the final section of the oil uptake curves, the amount of oil absorbed over time at high temperatures was not statistically significant. According to Dorani et al. (2007), this could be due to the compact structure formed in the product, which acts as a barrier to oil penetration. Nevertheless, kinetic constants can be used to describe the mass transfer of moisture and oil [26].

4-5. Moisture and Oil Transfer Kinetics

Figure 8 illustrates the linearized moisture transfer model through the natural logarithm of dimensionless moisture content from the beginning of the process. By calculating the slope of the regression lines fitted to the natural logarithmic data, the moisture reduction kinetic constant (kw) was obtained for the frying temperatures of 160, 180, and 200°C, as 0.1669, 0.1789, and 0.184 s^{-1}, respectively. As expected, increasing the frying temperature resulted in a higher moisture reduction constant, indicating a faster moisture loss from the product at higher temperatures compared to lower ones. Mohebbi et al. (2011) reported that the final moisture content of the product decreased with increasing frying temperature due to the more rapid release of water mass. Additionally, increasing the frying time limited the rate of moisture reduction [27].

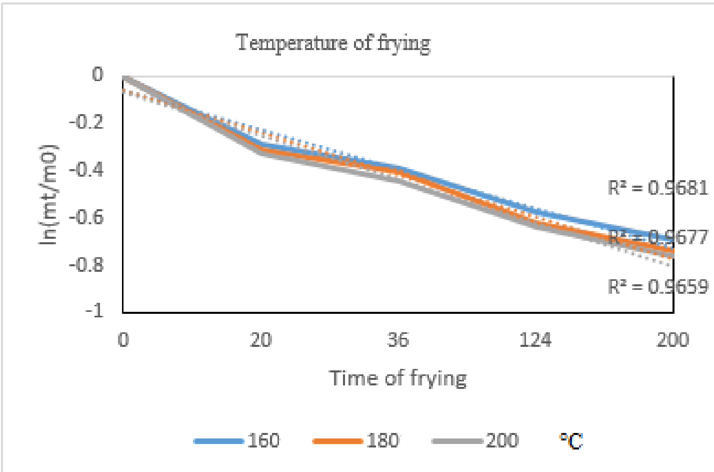

Figure 8. Linear fitting of a natural logarithmic moisture transfer model (from the beginning of the process)

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Figure 9 illustrates the fitting of the kinetic model for oil absorption. According to Table 1, the kinetic constant of oil uptake increased moderately with rising frying temperature. On the other hand, the total information obtained from the curve fitting confirmed a reduction in oil absorption at higher temperatures. These findings are consistent with the results of Kita et al., who observed that potato chips absorbed less oil at elevated temperatures [10]. Similarly, Dorani et al. reported that during frying at 180°C, only 38% of the oil content penetrated into the potatoes, while 62% remained on the surface, which aligns with the findings of the present study [26]. The variation in the oil absorption kinetic constant showed only a slight increase with rising oil temperature.

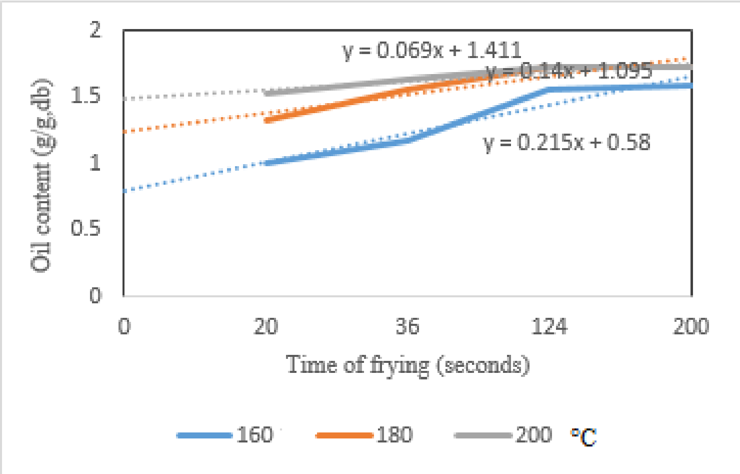

Figure 9. Linear fit of a kinetic model of oil absorption

Table1- Fitting information of oil adsorption kinetic model

Oil Temperature (°C)	Equilibrium Oil Content OeqO_{eq}Oeq (g/g, db)	Oil Uptake Rate Constant K0K_0K0 (1/s)
160	1.59	0.024667
180	1.73	0.026771
200	1.73	0.045643

6.4. Convective Heat Transfer Coefficient

The heat transfer coefficient is one of the most important parameters for maintaining the quality of fried products. During the boiling phase, it plays a critical role in developing the sensory attributes of the product, promoting browning reactions (Maillard reactions), and caramelization reactions, all of which contribute to the full development of flavor, color, and texture. The quality of the crust formed during the boiling phase is a key factor influencing the heat transfer rate and the desired texture of the product. Moreover, thermal flow within the food matrix requires consideration of boundary conditions in heat transfer equations, using the convective heat transfer coefficient. Therefore, measuring the convective heat transfer coefficient is essential to better understand the complexities of the frying process [28]. As shown in Figure 10, the convective heat transfer coefficient (hhh) was higher during the initial phase of frying and decreased over time. The highest hhh value was recorded at the 20th second at a frying temperature of 200°C. The obtained heat transfer coefficient values showed a linear dependency on the product's moisture loss rate, with the maximum hhh occurring at the point of peak water evaporation and maximum oil turbulence. After surface drying and the reduction of oil turbulence, despite the surface temperature of the product approaching the oil temperature, the heat transfer coefficient remained relatively constant. This indicates that hhh is strongly influenced by bulk movement and flow turbulence in the heating medium.

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As the frying temperature and time decreased, the hhh value also declined. At the start of the process, the coefficient reached its peak due to intense evaporation and turbulence and then decreased as the boiling rate and turbulence subsided. For different oil temperatures, the maximum hhh value was reached almost simultaneously, which further emphasizes its dependency on oil turbulence and the evaporation phase. At higher oil temperatures, due to greater moisture loss and more intense turbulence, a higher maximum heat transfer coefficient was observed [29].

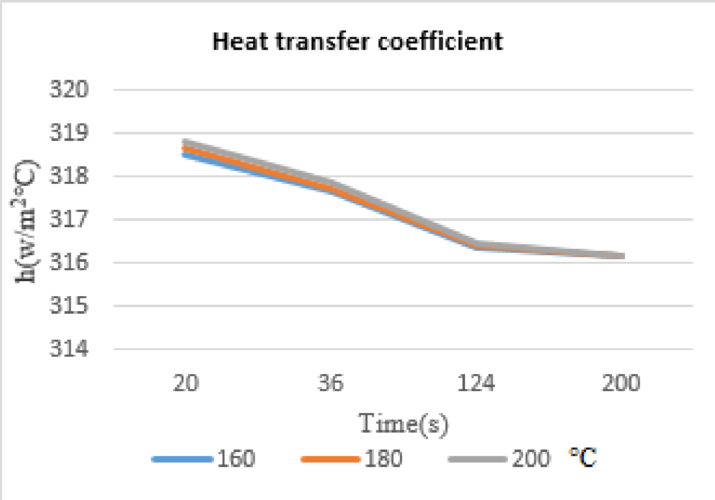

Figure 10: Changes in convective heat transfer coefficient of displacement over time

6-4. Convective Heat Transfer Coefficient

In a two-stage frying process control, the first stage controls the rate of heat input to the raw materials and oil, which is crucial for process optimization and efficiency in the second stage [14]. In the frying process, heat is transferred from the heating medium (oil) to the surface of the food through convective heat transfer, and then enters the food through conductive heat transfer. Water plays several roles in heat transfer and cooking the food during the frying process. The first role of water is to absorb thermal energy from the hot oil that surrounds the food. This process helps prevent the food from burning due to excessive dehydration (hydration) by removing energy from the food's surface. Therefore, although the oil temperature may reach 180°C, the food's temperature is only around 100°C, which corresponds to the boiling point of water in the food under atmospheric pressure. The excess heat is used to convert water from liquid to vapor [25].

Frying actually consists of four stages: initial heating (natural convective heat transfer with no evaporation), surface boiling (crust formation and forced convective heat transfer), the decreasing rate stage (thickening of the crust, the longest stage), and the end-point of bubble formation [30]. The crust, whose thickness increases during frying, is characterized by two factors: first, the temperature in this region is higher than the boiling point of the liquid in the food, and second, the concentration of liquid water in it is negligible [31]. As thermal conductivity in the crust decreases, it impacts both heat and mass transfer, resulting in a reduced dehydration rate. The rate of heat transfer depends on the temperature difference between the food and the heated fluid and the surface thermal conductivity coefficient [32].

The methods reported in literature for measuring the heat transfer coefficient during immersion frying have several limitations. These include the lack of standardized methods for measurement, neglecting mass transfer in most cases, overlooking the effects of product accumulation, and inconsistencies in estimation and reporting of measurement errors [9].

Sahin et al. observed that during the frying of potatoes, the convective heat transfer coefficient (hhh) increased with the oil temperature. After crust formation, the heat transfer coefficient decreased due to the reduced evaporation rate, which is the factor causing oil turbulence. Moreover, as bubbles from water vapor rise to the upper surface of the oil, the convective heat transfer coefficient at

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the upper surface becomes lower than at the lower surface due to the insulating effect of the water vapor bubbles at the upper surface [33].

Farkas and Hobart studied heat transfer in frying as a fast method for drying food. The results showed that a complex system of natural and forced convective heat transfer, along with boiling conditions, is involved in frying. The convective heat transfer coefficient was calculated to be between 300 and 1100 W/m²·°C, largely dependent on the bulk movement and oil turbulence. Thermal flow increased as the oil decomposed, which was due to the reduction in bubble size and an increase in bubble number resulting from changes in the oil's interfacial properties. With the increase in crust thickness, a thermal barrier between the oil and the food was formed, reducing the rate of heat transfer, followed by a decrease in vapor formation and reduced oil turbulence [34].

Yildiz et al. (2007) estimated the convective heat transfer coefficient using the linear section of the natural logarithmic temperature and moisture ratio curve against time. Their method, based on measuring temperature over time in potatoes, did not require knowledge of the thermocouple position, which reduced experimental error. Their results showed that the heat transfer coefficient decreased with increasing oil temperature. The estimated values of the heat transfer coefficient were 287±8, 227±8, and 181±7 W/m²·°C for oil temperatures of 150, 170, and 190°C, respectively. The increase in moisture evaporation rate at higher frying temperatures consumed more energy for vaporization, thereby reducing the energy available for internal temperature changes in the food, which led to a decrease in the effective heat transfer coefficient, contrary to the findings of this study [18].

According to Costa et al.'s results, during frying, nucleate boiling was observed, where water vapor formed as bubbles on the surface of the potato samples and moved toward the upper part of the oil bed. The movement of vapor bubbles after formation at the surface significantly impacted oil turbulence. Bubbles released from the lower surfaces merged and formed larger bubbles at the surface, which could act as a resistance to heat transfer. It was predicted that the heat transfer coefficient at the lower surface of the product would be lower than at the upper surface. The results of this estimation showed that the convective heat transfer coefficient increased with the decreasing moisture content during the first 50 to 60 seconds of the process, which is consistent with the observations of this research [21].

As reported by Farkas and Hobart, while surface boiling causes water to vaporize, oil turbulence increases the convective heat transfer coefficient, reaching its maximum. The maximum drying rate of the product and the decrease in the convective heat transfer coefficient both occurred around 60 seconds after the start of the process. The increase in crust thickness during this time created a thermal barrier between the oil and the food, as well as between the oil and the vapor phase, acting as an insulating layer [34].

Baik and Mita also stated that when the product's surface temperature reaches about 100°C, water quickly evaporates from the food due to the high oil temperature, causing severe turbulence and bubble formation [22].

5. Conclusion

In this study, the effect of time and temperature variables on the quality characteristics of deep-fried eggplant was investigated. The results of the simulation of oil and moisture content in deep-fried eggplant are summarized as follows: As the frying time increased, moisture decreased, resulting in higher oil absorption. Therefore, using shorter frying times and lower temperatures can prevent moisture loss and, ultimately, reduce oil absorption in the samples. According to the results, the convective heat transfer coefficient was higher in the initial stages of the process and decreased as frying time progressed. The highest hhh value was recorded at the 20th second at a frying temperature of 200°C. The greatest oil absorption occurred in the early stages of the process. Hence, high temperatures, by increasing evaporation intensity and reducing the process time, can effectively reduce the final oil content of the product during frying under atmospheric conditions.

6.Reference

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مقاله علمی_پژوهشی

شبیه سازی محتوای رطوبت و جذب روغن در فرآیند سرخ کردن ناپیوسته بادمجان

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چکیده

بادمجان به دلی رطوبت بالا و نرم شدن بافت طی مدت زمان نگهداری، عمر ماندگاری کوتاهی دارد. بنابراین استفاده از روش‌های مناسب برای فرآوری، افزایش زمان نگهداری و حفظ ارزش تغذیه‌ای آن ضروری می‌باشد. در واقع درک انتقال حرارت و جرم در طی سرخ کردن می‌تواند برای بهینه سازی و کنترل هرچه بیشتر فرایند مفید باشد. در این پژوهش اثر سرخ کردن در دماهای ۱۶۰، ۱۸۰ و ۲۰۰ درجه سیلسیوس به مدت‌های ۲۰، ۳۶، ۱۲۴ و ۲۰۰ ثانیه برمحتوای رطوبتی، محتوای روغن، سینتیک انتقال رطوبت و روغن و تخمین ضریب انتقال جابه جایی انجام گرفت. نتایج نشانداد نمونه سرخ شده در دمای ۱۶۰ درجه سیلسیوس به مدت ۱۲۴ ثانیه، کمترین میزان جذب روغن را دارند. همچنین مشخص شد با کاهش دما و زمان سرخ‌کردن محتوای روغن نمونه‌ها کمتر می‌گردد. به‌علاوه، مدل‌های تجربی، به خوبی داده‌های آزمایشی را برازش نمودند. علاوه بر این، نتایج نشانداد که نمونه سرخ شده به مدت ۲۰۰ ثانیه در دمای ۲۰۰ درجه‌ی سیلسیوس کمترین میزان نسبت محتوای رطوبت را دارد. همان‌طور که مشخص است با افـزایش دمـای سرخ کردن ثابت سینتیک کاهش رطوبت افزایش یافت که نشان‌دهنـده سرعت خروج رطوبت بیشتر از محصـول در دمـای بـالا نسـبت بـه دماهای پایین‌تر بود. همچنین، افزایش زمان و دمای سرخ کردن موجب کاهش محتوی رطوبت نمونه‌ها گردید. ضریب انتقال حرارت جابجایی در زمان‌های اولیه فرآیند بیشتر بوده و با سپری شدن زمان سرخ کردن این عدد نیز کاهش یافت. بیشترین مقدار h مربوط به ثانیه بیستم در دمای سرخ کردن ۲۰۰ درجه سیلسیوس بود.

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