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Experimental study on transport mechanisms during deep fat frying of chicken nuggets

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ABSTRACT

Two important factors affecting oil uptake of food products during deep fat frying (DFF) are water content and pressure development. This study tries to explain the complex mass transfer mechanisms taking place during DFF with respect to real time pressure variations inside chicken nuggets. Breaded chicken nuggets were made with and without 5 g/100 g methylcellulose (MC) added to predust. Frying experiments were performed at 175 °C and 190 °C for 0, 30, 60, 120 and 240 s. The gage pressure increased rapidly after the nuggets were introduced into hot oil. As frying progressed the pressure inside the nugget decreased to negative values (suction). During post frying cooling there was a further reduction in pressure. The MC-coated nuggets had lower fat uptake and moisture loss than control nuggets for both frying temperatures. Scanning electronic microscopic analysis showed that the control nuggets had greater randomness in the crust, core and meat layers in terms of microstructure development, surface texture, rigidity and pore sizes than MC-coated nuggets. Higher frying temperature resulted in increased complexity of microstructure. The nuggets fried in dyed oil showed oil penetration up to 1–4 mm into the meat layer. This implied that the oil uptake was a surface phenomenon.

1. Introduction

Deep fat frying (DFF) is an intensive heat transfer process, which is expected to produce significant internal vaporization and pressure generation as a function of the porous structure of the product (Ni & Datta, 1999). Deep fat frying can be defined as the process of cooking foods by immersing food into the frying oil with a temperature of 150–200 °C, which is well above the boiling temperature of water (Farkas, Singh, & Rumsey, 1996).

The water evaporation is quite rapid initially during frying. This process is obstructed by the formation of the thick crust; as a result pressure starts building inside the product due to the accumulation of excess vapor and results in the formation of cracks in the crust. These cracks serve as conduits for the oil entry into the product (Mittelman, Mizrahi, & Berk, 1984). Mallikarjunan, Chinnan, Balasubramaniam, and Phillips (1997) observed a reduction in the moisture content with increase in frying time due to evaporation. As the frying progresses, a moving moisture front advances into the chicken drum body. This moving front separates the wet and the dry regions and results in moisture transfer in vapor mode. The liquid mode of moisture transfer is thus slower than the vapor mode (Mallikarjunan et al., 1997).

The primary microstructural changes produced during frying are starch gelatinization and protein denaturation (Llorca, Hernando, Pérez-Munuera, Fiszman, & Lluch, 2001; Prabhasankar, Indrani, Rajiv, & Rao, 2003). The microstructure of chicken is made up of complex, heterogeneous, porous, anisotropic structures (Kassama, Ngadi, & Raghavan, 2003), which are hygroscopic in nature. The porosity and pore sizes of fried foods tend to decrease with the frying time. Pinthus, Weinberg, and Saguy (1995) elucidated that the reason for reduction in pore size with frying time is the oil uptake phenomenon. Keller, Escher, and Solms (1986) directly visualized the porous surface region filled with dyed oil in French fries. Moreira and Barrufet (1996) used nuclear resonance imaging on alginate gels at 170 °C and found that oil concentrates on the edges and at the puffed regions. Vitac (2000) observed the development of a heterogeneous porous structure in cassava chips by scanning electron microscopy. Pedreschi, Aguilera, and Arbildua (1999) observed that the oil was trapped inside the potato cells as a result of cell rupture in the form of an 'egg box' by confocal observations. The amount of oil on the crust was found out to be six times as compared to the amount of oil in the core region of French fries (Aguilera & Gloria, 1997). The results from various frying experiments show that the location of oil was mainly on the crust

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as well as in the regions around the middle layer of cells just beneath the crust, and the core was virtually oil free (Keller et al., 1986). The oil uptake was considered to involve a balance between the capillary forces and oil drainage during the post-frying cooling period (Ufheil & Escher, 1996). Gamble, Rice, and Selman (1987) suggested that most of the oil is pulled into the product when the product is removed from the fryer due to the condensation of the steam, which produces a vacuum effect. Moreira, Sun, and Chen (1997) found that nearly 64 g/100 g of the total oil uptake into the product takes place only during cooling and out of this 80 g/100 g remains on the surface and the rest (20 g/100 g) is absorbed into the product.

To our knowledge, the experimental information about the physical pressure measurement during frying is scarce. This could be due to experimental difficulties at high frying temperatures and the involvement of small sample sizes. In the most past studies, computer models have been used to estimate the dynamic pressure changes inside the DFF products. Ni and Datta (1999) calculated gage pressure as 1 kPa in a potato slab after 10 min of frying. Halder, Dhall, and Datta (2007) calculated the gage pressure inside DFF potato slabs as 0.5 and 0.8 kPa at 1 and 16 min of frying, respectively. Yamsaengsung and Moreira (2002b) predicted that the average pressure inside the tortilla chips is 284 kPa after 60 s of frying. Such high pressure is expected to blow up the tortilla chip as noted by Halder et al. (2007). Thus, there are disagreements in the literature about the modeling based pressure values. The oil absorption depends upon the radius of the pores. The small pores create high capillary pressure, which results in higher oil content (Moreira et al., 1997). The solid food matrix is an obstacle to the water bubble growth. This leads to an overpressure inside the food during frying. The extent of overpressure depends upon the structure and material of the food. Vitac (2000) found this overpressure to be 45 kPa inside the alginate gel, which contained 10 g/100 g starch during frying. The over pressurization depends upon the initial structure of the material. If the structure is weak, the material may break allowing the liquid and steam to escape. Vitac (2000) also measured a pressure dip of 35 kPa in the food model gel (alginate with 10 g/100 g starch) after few seconds of removal from the fryer. He concluded that vacuum is the most important force responsible for oil uptake in porous foods.

The current research tries to explain the DFF by relating the real time pressure variation inside the product with mass transfer processes and microstructural changes. The primary objectives of this research were: to measure the pressure changes inside control and methylcellulose-coated chicken nuggets at three different levels of initial moisture contents by a fiber optic pressure sensor at different frying temperatures; to measure the fat and moisture changes in control and methylcellulose-coated chicken nuggets at different frying times and temperatures; to analyze the microstructure of chicken nuggets by scanning electron microscopy (SEM); and to observe the fluid transport phenomenon in the chicken nuggets by use of thermostable Sudan red dye and light microscopy.

2. Materials and methods

2.1. Sample preparation

The chicken nuggets were prepared at a commercial food processing company. The primary ingredients for the chicken nugget formulation were boneless chicken (breast and thigh meat), batter, and breading ingredients. The batter and breading ingredients (predust) were obtained from Kerry Inc., Beloit, WI. The skin portion of the meat was not added to the formulation. The coating included two treatments. The first set had a predust (No. 53650) coating with 5 g/100 g MC food grade gum, commercially known as Methocel A4M. The second set of nuggets did not have the MC coating in the predust (Predust Control G7102) formulation and this set of nuggets were the control nuggets. The addition of 5 g/100 g methylcellulose (MC) did not change calories, taste or odor of the food, because MC is metabolically inert and indigestible. MC was obtained from Dow Chemical, Midland, MI, U.S.A. The batter (No. G4113) and breading (No. G3684) were used. The primary ingredients for the uncooked chicken meat constituted breast meat (48 g/100 g), boneless thigh meat (42 g/100 g), water (9.1 g/100 g), salt (0.5 g/100 g) and phosphate (0.4 g/100 g) together constituting about 31.75 kg. The chicken used was boneless and skinless in order to reduce in homogeneities. Each chicken nugget had a diameter of about 4.2 cm, thickness of about 1.27 and weighed 18 g. The nuggets were par fried at 175 °C and 190 °C for 26–30 s with regular soybean oil. The parfrying helped to stabilize the coating on the nuggets. The MC nuggets were prepared in the 1st batch followed by the second batch of control nuggets. The equipment was washed thoroughly after the first set of nuggets was formed in order to prevent mixing of the two different predust applications. Finally, the nuggets were packed, labeled with specific treatment name and the parfrying temperature, and sent to the blast freezer for storage. The frozen samples were shipped overnight to Texas Tech University in insulated boxes with dry ice (solid carbon dioxide coolant). The samples were then stored at −12 °C during the course of experiments to prevent deterioration.

2.2. Pressure measurement

The effect of initial moisture content on the gage pressure created inside the chicken nuggets during DFF was measured by means of a fiber optic pressure sensor (FISO Technologies Inc., Québec, Canada). The sensor was attached to a FTI-10 Fiber optic conditioner and controlled by FISO Commander-2 software (Version R9, FISO Inc., Québec, Canada). The pressure sensor is designed for measuring high temperature, short time processes like frying. The maximum temperature tolerance limit for the sensor was 450 °C. Pressure was measured in kPa at 1 s intervals. The ambient gage pressure was considered as 0 kPa for all experiments. The pressure sensor was inserted into a chicken nugget from its lateral side up to a depth of 1.5 cm toward the center. The sensor tip had a diameter of 2 mm.

The temperature changes in the nugget and frying oil were monitored simultaneously along with the pressure using K-type thermocouples attached to a data logger (NI USV 9161, National Instruments, Austin, TX) controlled by Lab View software (Version 8.2.1, National Instruments, Austin, TX). The temperature was recorded for every 1 s. The thermocouple was inserted in the opposite direction to the pressure sensor on the lateral side of the chicken nugget up to 1.5 cm (Fig. 1). The frozen chicken nuggets

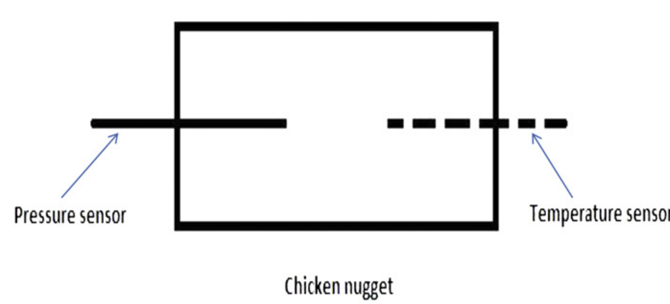

Fig. 1. Pressure (solid line) and temperature (dotted line) sensors inserted into the nugget in opposite directions.