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Heat transfer coefficients during deep fat frying of sweetpotato: Effects of product size and oil temperature

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Abstract

Heat transfer coefficient, *h* during deep fat frying of sweetpotato was determined from designed experiments. Samples of three different disc sizes were fried at four oil temperatures between 150 and 180 °C. Heat transfer coefficient estimation was based on heat energy balance between the oil and sample during frying. Maximum *h* was reached at the earlier stage of frying (80–120 s). The range of maximum *h* reached was 710–850 W/m^2 °C. *h* at latter period of frying (200–300 s) was 450–550 W/m^2 °C. *h* was found to vary directly with oil temperature but inversely with sample size ($p < 0.05$).

Keywords: Deep fat frying; Heat transfer; Moisture transfer; Heat transfer coefficient; Thermal properties; Sweetpotato

1. Introduction

Sweetpotato (*Ipomoea batatas*) is an important crop with a large starchy sweet tasting tuberous root. It is a tuberous-rooted perennial crop with prostrate and slender stems. Both yellow and white types of sweetpotato exist, the colour being of the flesh. The yellow type is preferred because of the attractive colour, good flavour and cooking qualities (Rodriguez, Raina, Pantatisco, & Bhatti, 1975). However, it is not as sweet as the white type. Sweetpotato is an exceptionally rich source of Vitamin A (7100 IU/100 g). It also has appreciable quantities of ascorbic acid, thiamine, riboflavin, niacin, phosphorus, iron and calcium (Picha, 1985; USDA, 1984). Sweetpotatoes are usually consumed after baking, boiling, steaming, frying or it may be candied with syrup, sliced into chips, or pureed. Deep fat frying is a popular method used in processing sweetpotato into French fries or chips. In this process, the sweetpotato slices are cooked by immersion in an edible fat or oil at a temperature between 150 and 200 °C. Frying is a very turbulent process. Turbulence is associated with the existence of random fluctuations in the fluid. Transport of heat, mass and momentum in a turbulent boundary layer is attributed to motion of eddies, which are small portion of fluid in the boundary layer that move about for a short time before losing their identity. The process is quite complicated to describe theoretically. In modeling the frying process, there is a need to determine the convective boundary conditions in heat and mass transfer. One of the major factors that govern the rate of heat and mass transfer during frying is the convective heat transfer coefficient, *h*. Both direct and indirect methods of measuring *h* exist in literature. The indirect method is more common since it avoids all the complexities of measuring temperature during frying. The method uses metal pieces as heat flux meters to simulate food sample's hydrodynamic conditions. The method however does not provide very accurate estimations most especially during the bubbling stage of frying since the metal pieces usually unavoidably change the nature and pattern of flow of the vapour bubbles originating from the food. Baik and Mittal (2002) reported that *h* value during frying is affected by bubble flow direction, velocity,

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Nomenclature

A	area (m^2)
C_p	specific heat capacity (J/kg °C)
d	sample diameter to thickness ratio, i.e. D/L
ΔT	$T_\infty - T_s$ (°C): this parameter reflects progress during frying
h	heat transfer coefficient (W/m^2 °C)
L_v	latent heat of evaporation (J/kg)
M	mass of sweetpotato sample (kg)
m	moisture content, decimal (wet basis)
T	temperature of sweetpotato (°C)
T_∞	oil temperature (°C)
T_s	sweetpotato's surface temperature (°C)
t	time (s)
$t2$	temperature of the position along sample thickness of sweetpotato between the top and center
$t4$	temperature of the position along sample thickness of sweetpotato between the bottom and center of sample
W	moisture content of sweetpotato (kg)

bubble frequency and magnitude of oil agitation. Direct method, even though more challenging, provides better estimates of h. A study reporting heat transfer coefficient of sweetpotato during deep fat frying is not available in literature. The objective of this study is to determine h of sweetpotato during deep fat frying and investigate the effects of sample size and oil temperature on the coefficient.

2. Materials and methods

2.1. Sample preparation

Sunny II sweetpotatoes (*Ipomoea batatas*) were bought in 20 kg lots from an oriental grocery store (Saskatoon, Canada) to avoid variability in quality and product chemistry. The products were stored in a cooling chamber at a temperature range of 13–16 °C and relative humidity 85–90% usually for 24 h before use to maintain quality (Kotecha & Kadam, 1998). The tubers were manually peeled with a hand peeler and then cut into discs using a cylindrical borer and a knife. Samples were cut into discs having diameters 2.5, 3.5 and 4.0 cm, all with 1 ± 0.1 cm thickness. Canola vegetable oil (Sunnyfresh limited, Toronto ON) was used as the frying oil in this study.

2.2. Sample holder

Frying is a very turbulent process in which the product moves around randomly in the oil. One of the major challenges of studying the process is in making the product stable enough so as to be able to measure its temperature. For this study, a sample holder (Fig. 1) was designed and fabricated. It essentially has a handle part made of Teflon which holds the product and the steel frame that ensures product's stability in the turbulent oil. One of the handles was adjustable so that the holder can handle multiple sizes. Three holes were bored into the other handle to accommodate thermal probes which measure the temperature within the sweetpotato (Fig. 1). Making the arm of a poor conductor of heat like Teflon ensures heat conduction to sample is limited to oil only and does not involve heating from sample holder arm.

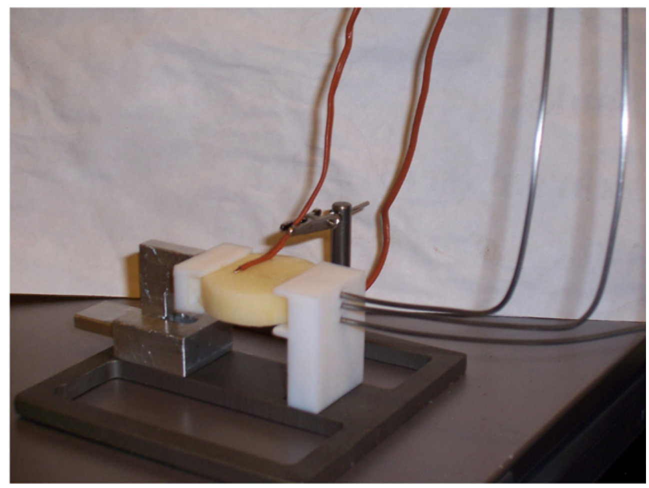

Fig. 1. Sample holder with the sample and thermocouples inserted.

2.3. Experimental procedure

A domestic deep fryer (Cool touch deep fryer, General Electric, Mississauga, ON) was used in this study. The fryer with a capacity of 2 l has a built-in on-off thermostat for oil temperature regulation. It also has a temperature indicator but a K-type thermocouple was also used to indicate oil temperature during frying. A temperature controller, Proportional controller Model 6102 (Omega Inc. Stamford, CT.) was used to regulate oil temperature fluctuation, ±1 °C during frying. The sample disc was fixed inside the sample holder (Fig. 1) and the sample holder adjusted with a tight-screw to ensure sample was tightly held. Three thermal probes made from T-type thermocouple were inserted into the sample through the guide holes in the fixed arm of the holder. Two of these thermal probes were inserted into the sample at a point that is 1 mm from either surface while the third thermal probe was inserted at the centre of the sample. Two other T-type thermocouples were tightly pressed to the surface of the product by a couple of alligator clips built into the sample holder (Fig. 1). Two litres of Canola oil was poured into the deep fryer up to the *max* mark. Fryer was switched on and its temperature was set to 150 °C. After the oil temperature has reached the desired