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Capacitive sensor probe to assess frying oil degradation

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The repeated usage of frying oil has been proven hazardous due to the degradation process by chemical reactions that lead to changes in the quality of the oil. Currently, the degree of frying oil degradation is indicated by the percentage of its total polar compounds (TPC). In this study, a capacitive sensor was designed to assess frying oil degradation at several heating time intervals by measuring changes on its electrical capacitance. The sensor was designed using interdigitated electrode structure. A total of 30 samples of 130 ml palm oil were heated at 180 °C up to 30 h. For each one hour interval, one sample was moved out from the laboratory oven. The electrical capacitance, total polar compound (TPC) and viscosity of the samples were measured for analysis. Preliminary results demonstrated significant correlation between oil electrical capacitance with TPC and viscosity with R^2 ranged from 0.83 to 0.90. The designed sensor has good potential for simple and inexpensive way of determining frying oil quality.

1. Introduction

Frying is one of the earliest and most popular ways of cooking. It is the process that food is submerged into the hot oil or fat at elevated temperatures (150–190 °C). It gives tasty flavor and charming appearance in food which is very simple and fast in operation as it requires a limited amount of time in food preparation [5]. During the frying process, in the presence of air and moisture many chemical reactions occur, such as hydrolysis, polymerization and thermal oxidation, thereby producing a considerable number of harmful compounds such as polymer and ketones, which significantly change the quality of the frying oil [7,13,24,35,37]. In addition, improper methods to determine the time to discard the oil will result in over using it which poses a public health risk [16,22].

In most cases frying oil degradation is evaluated based on visual inspection wherein for instance the chefs experience to decide when to discard the oil for example based on excessive foaming, odor, smoking, color changes, and by tasting the food products. However, these are not reliable methods due to their subjective nature and these parameters may manifest only when the oil has already become unsafe to be reused. Studies on both physical and chemical characteristics of the

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Table 1 – Physical and chemical Indicators of frying oil quality.

Physical indicators	Chemical indicators
Smoke point	Free fatty acids (FFA)
Color	Peroxide value (PV)
Viscosity	Iodine values (IV)
Taste	Total polar compounds (TPC)
Odor	Polymeric triglycerides
Foam persistence	Anisidine value (AV)
	Polymerized and oxidized material

frying oil are important to determine the deterioration level of the oil [6].

Several physical indicators (Table 1) are used to evaluate the quality of frying oil: smoke point, color, viscosity, taste, odor, and foam persistence [24,31,35]. These tests are extensively used; however they are not decisive in themselves. Color, for example, basically depends on the sort of food fried as well as the oil; taste and odor depend on the food type used for frying. Smoking amount of frying oil is related to the temperature as well as to the amount of low molecular weight breakdown in the oil. Viscosity measurements can be used as an indicator to detect the quality deterioration of frying oil, but it is not conclusive in itself.

While the chemical indicators listed in Table 1, can be a more reliable way to assess the deterioration of frying oil [22]. Innawong et al. [16] stated that the volatile compounds produced from chemical reactions through frying process contribute to raise the peroxide value (PV) in the oil. Tsuzuki et al. [34] argued that PV increases with time as the oil is heated at 180 °C. In addition, iodine value (IV) is used for the assessment of the suitability of the oils [23]. Garba et al. [12] reported that oil with high IV exhibited poor performance due to the oxidation reactions of lipids and the hydroperoxide formation between the unsaturated fatty acids and oxygen. Also, free fatty acid (FFA), polymeric triglycerides, anisidine value (AV), and polymerized and oxidized material (POM) are broadly used as the pointers of the frying oil quality, but are not conclusive in themselves [21]. At present, measurement of the total polar compounds (TPC) is considered to be the most commonly used method to evaluate the quality of oil because it determines overall chemical degradation taking place in the oil [10].

To date various methods have been developed and introduced to measure the different chemical and physical parameters of frying oil. For example, chemosensory system for controlling the quality of oil in food industries [36], Fourier transforms infrared (FTIR) to differentiate between good and inadmissible oils [17], chromatography to measure dielectric constant, smoke point and viscosity [28] and image analysis to determine the TPC rate in frying oil [14]. However, these methods are complicated, time consuming, and expensive. Thus, developing a simple sensing system to help in appraising the quality of frying oil is required.

More recently, there are many instruments and kits that can be used to determine oil degradation. For example, viscosity meters and electronic-based physical tests such as Vibro Viscometer (A&D Company Limited, Japan) can be used to observe frying oil at all stages of its used and determine its viscosity [11]. Other than that, instruments such as Testo 270 (InstruMartlnc, Germany), and Ebro FOM 310 (ebro®Electronic GmbH, Germany) were developed by electronic companies to measure the quality of frying oil by testing the total polar materials (TPM) based on changes in the dielectric constant of the oil. In addition, kits such as Fritest (E. Merck, Germany) and Oleh TestTM (Panreca, Spain) were developed to measure the quality of frying oil by testing the FFA and TPC, respectively based on the color reaction of the oil [9,37]. However, there are some limitations with the current devices such as complex calibration requirement, suitability for different type of oil as well as distinct temperature dependencies [27].

Numerous studies have attempted to explain the molecular polarizability and the orientational effects of polar media by observing changes in their electrical properties. Morgan et al. [25] reported that the dipole moment of the biological particles is induced when subjected to an AC field. Where the polarized particles gain a force that can cause them to replace to electric field, relying on the particle polarizability as comparing to the suspending medium. The molecular polarizability is effecting the magnitude of the dipole moment, and this in turn is controlled by the dielectric properties of the medium and molecular. Bagchi et al. [4] stated that the values of the polarizability of the molecule can experience substantial changes from their values when a molecule is excited to higher electronic state. According to Hughes [15] a molecule experience negative or positive dielectrophoresis is relying on its polarizability relative to its nearby medium. As Hughes noted that the variances in the quantity of induced charge at the interface between medium and particle lead to oriented dipole counter to applied field where the polarizability of medium is less than that of molecule, and in the same direction as the applied field where it is less. The relative polarizability depends on applied field frequency, it has a strong frequency dependence, beside the conductivity and permittivity, because it is a complex function. According to Darma [8], the movement of dipole throughout polarization resulting in displacement current, and this contributes to total current and improves the conductivity.

Generally, studies on changes of electrical properties have been introduced and some sorts of instruments were proposed to be used in the agricultural field [17]. The parallel planar electrodes are one of the generally used probes to sense the moisture content in peanut oil [18], analysis of eggplant pulp and effects of drying and freezing–thawing treatments on its capacitance characteristics [38]. Presently, interdigitated electrodes (IDEs) are applied in many sensing devices including surface acoustic wave, chemical sensors, and MEMS biosensors [33]. Furthermore, IDEs have been studied in cancer cell detection as well as other biological associated applications [3,19]. Therefore, IDE could be used in solving complex calibration requirements and improving the accuracy of sensory sensitivity. Also, IDE shape has some advantages such as no moving parts, ease of fabrication, flexible in design, and cost effective [30]. In this study, a capacitive sensor was designed using IDE platform to assess frying oil degradation due to heating at different frequencies. The aims of this study were to develop and evaluate a new sensor for