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Towards a wicking rapid test for rejection assessment of reused fried oils: Results and analysis for extra virgin olive oil

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ABSTRACT

This work investigates the potential of developing a rapid test based on wicking of oil into paper for determining whether a reused frying oil is to be rejected. To achieve this goal, wicking patterns (oil penetration rate and oil front shape versus time) of both fresh and prolonged fried extra virgin olive oil are optically registered at six different paper stripes. Four of them are double-ply towel papers whereas the other two are single-ply chromatographic papers. Wicking tests are performed at 20 °C and 30 °C. It is shown that the type of paper affects seriously the wicking patterns. Double-ply papers present high oil penetration rates but very irregular oil front shapes whereas single-ply papers yield lower oil penetration rates but pretty flat oil fronts. Furthermore, it is found that only under certain conditions the penetration rates obey the well known Lucas–Washburn equation. A discussion is made on the phenomena that take place during wicking of oil into paper which may cause deviations from the Lucas–Washburn equation. A semi-empirical model is proposed to describe the above deviations by incorporating the effect of time evolving pore sizes.

1. Introduction

The intense and complex heat and mass transfer processes during deep fat frying result in significant oil degradation (Bouchon et al., 2003) which imposes oil replenishment in sequential frying batches. The determination of the exact instant that frying oil must be replenished is a major concern for avoiding possible health risks (Bansal et al., 2010a) but also for estimating the cost of fried foods in food industry and catering applications (Kress-Rogers et al., 1990). The official analytical procedures used in laboratories to assess the quality of prolonged (or repeated) fried oils are very accurate but are also time consuming, expensive and cannot be used on the spot in industrial or catering applications. Hence, use of rapid tests is gaining attention in actual applications where there is need for quick evaluation of whether the total polar compound content of the oil has surpassed 25% by mass and so has to be discarded according to international laws (Bansal et al., 2010b; Paul and Mittal, 1997). A rapid test should exhibit the following characteristics: (i) correlate well with official analytical methods, (ii) provide an objective index, (iii) quantify the degree of oil degradation, (iv) be easy and inexpensive to use, (v) be independent from the nature of frying oil, (vi) have no influence from the fried food, and (vii) be safe to use in food production area (no toxic chemical, no glassware, etc.) (Gertz, 2000).

Gupta (2005) and Bansal et al. (2010a) in a comprehensive review categorized the existing rapid tests on those based on measuring physical parameters (i.e. color, dielectric constant and viscosity) and those based on measuring chemical parameters (i.e. total polar compounds, oxidized/free fatty acids and carbonyl compounds). Using an analytical laboratory method (size exclusion chromatography, HPSEC) Gertz (2000) determined polar materials, polymerized triglycerides and acid value of 150 different samples of deteriorated oil. He employed these results as reference to compare with and evaluate different commercial rapid tests based on the determination of chemical parameters (alkali colour number: *Fritest®*, and oxidation products: *Oxifrit-Test®*) and physical parameters (dielectric constant: *Foodoil Sensor™ - FOS™*, *Northern Instruments Corp.*, and relative viscosity and density: *Fri-Check®*). He found that the tests based on chemical parameters depend highly on the particular frying conditions (e.g. type of oil and food) and give poor correlation with analytical methods ($r^2 \sim 0.45$). On the contrary, physical parameters show good correlation with analytical methods ($r^2 \sim 0.894$). Marmesat et al. (2007) evaluated also the performance of several commercially available rapid tests in a significant number of fried oil samples (i.e. 105 samples). These rapid tests were based on changes of either oil physical properties (i.e. viscosity – *Viscofrit®*, dielectric constant – *FOS™*) or oil chemical properties (i.e. carbonyl compounds – *Fritest®*, total amount of oxidized compounds – *Oxifrit-Test®*) during frying. Similarly to Gertz (2000) these authors also observed that rapid tests based on

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physical properties give better results than those based on chemical properties.

Comparison among rapid tests based on physical parameters demonstrate that measuring the dielectric constant suffers from the tedious step to filter every sample before each test in order to remove traces of salt, water and minerals that enhance polarity (Gertz, 2000). Furthermore, Gertz (2000) showed that viscosity can be considered as a reliable physical parameter for rapid determination of oil quality, since the results obtained with *Fri-Check*®, are correlated very well ($r^2 = 0.917$) with the concentrations of polar materials and polymerized triglycerides. This was confirmed by Marmesat et al. (2007) who also reported that viscosity is a more accurate quality indicator than any other physical property. Very recently Osawa et al. (2012) used 59 different frying oil samples to evaluate the effectiveness of rapid tests based on oil's physical properties (viscosity tests: *Viscofrit*® and *Fri-Check*®; dielectric constant test: *Testo* 265). These authors argued that tests based on dielectric constant demand extremely careful calibration (i.e. by using an oil of well defined properties) before measurement and concluded, too, that viscosity tests are superior.

The above indicate that viscosity is a promising physical property to determine oil degradation in rapid tests. Two are the commercially known rapid tests that use viscosity as the examined parameter: i.e. *Fri-Check*® and *Viscofrit*®. *Fri-Check*® consists of an electronic system that measures the time needed for a piston-like body to free-fall inside a steel tube filled with oil. The fall time, which depends on oil's viscosity, yields automatically the polar compounds percentage, through a correlation function programmed in the software by the manufacturer (Stier, 2004). Testing requires 15 ml oil samples and lasts about 10 min because of several thermal regulation steps to a final sample temperature of 52 °C (Osawa et al., 2012). Although this device is valuable for rough estimations, its outcome may be seriously affected by dispersed particulates in the oil (unless filtered), poor temperature uniformity in the oil and end-effects due to the short length of the test tube. In addition, it does not allow adjustment to new types of oil besides those already incorporated in the correlation function and is rather complicated for techno-phobic people working in small scale catering enterprises and domestic users. On the other hand, *Viscofrit*® is based on the time spent to empty a funnel-like cone filled with the frying oil (Marmesat et al., 2007). It is simpler and faster than *Fri-Check*®, as the analysis takes less than 2 min but it requires approximately 30 ml of oil for a single test whereas calibration and oil filtration are needed before each test (since the presence of food particles in the oil may seriously affect measurements) (Marmesat et al., 2007). In addition, a good knowledge of oil temperature is needed (preferably between 20 °C and 30 °C) in order to interpret correctly the measurements.

Paper-based microfluidic sensors are emerging as a new technology for rapid tests in medical diagnostics for the developing world, where low cost, simplicity but also accurate results are essential (Martinez et al., 2010). Paper is already used extensively in analytical and clinical chemistry as a wicking medium (Martinez et al., 2010) because it is relatively cheap and abundant, sustainable, disposable, and easy to use, store, transport and modify. Paper has the unique property of being able to move fluids by capillary action without the need for power and effect separation of components in mixtures (Hossain et al., 2009).

Wicking of oil into paper is not a popular subject in literature. The vast majority of studies refer to wicking of aqueous solutions on porous solid matrices while a few other studies use alkanes as wicking liquids to maximize wettability of the solid (Van Oss et al., 1992). In our lab we have employed wicking experiments of alkanes into thin starch films in order to determine the effective pore size of these starch sheets (Kalogianni et al., 2004). Systematic efforts on wicking of non-polar liquids such as oil appear in printing applications (Daniel and Berg, 2006), in fibrous materials (e.g. candles and textiles) related applications (Patnaik et al., 2006) and in soil science (Ridgway et al., 2011; Chung et al., 2012). To our knowledge there is no study concerning the development of a paper based wicking rapid test for the determination of frying oil quality. This is indeed the objective of this work: to explore the potential of using thin paper sheets as a wicking medium to swiftly and accurately discriminate fresh from heavily fried oil. In

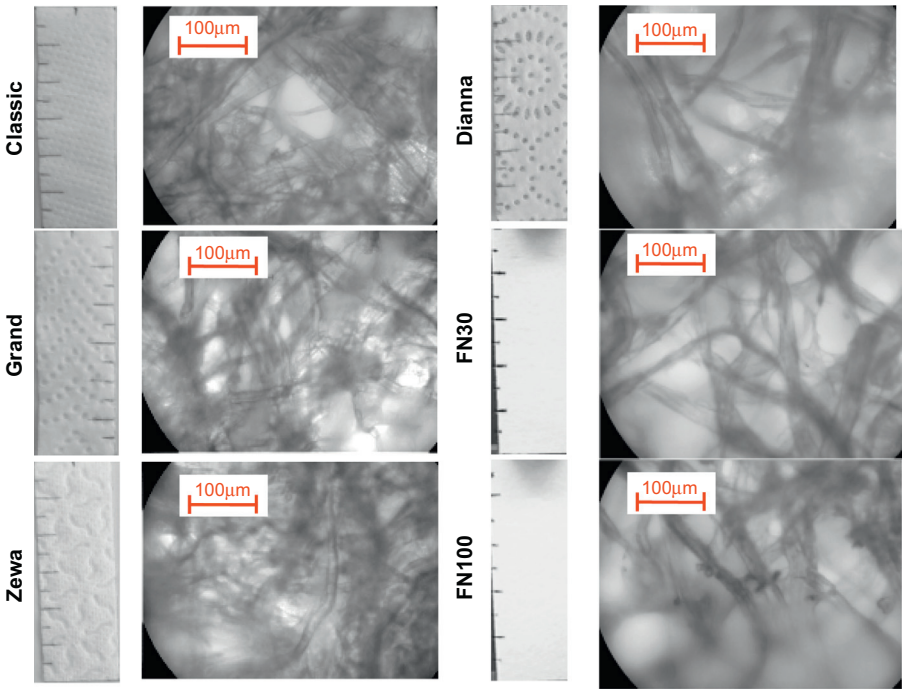

Fig. 1. Macroscopic and microscopic views of the wicking papers used in this study.