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Lubrication studies of fluid food using a simple experimental set up

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ABSTRACT

Studies of "oral" tribology and "oral" lubrication have attracted growing interests among food researchers because of their important roles in oral textural sensation. However, to access a feasible technique for such studies is still a challenge to many food researchers due to the high cost of a commercial tribometer. In this work, a simple experimental set up has been constructed and tested for its feasibility and reliability for lubrication studies. The ultimate aim is to develop a reliable and low-cost technique for food lubrication studies and oral texture sensation studies. The design is based on a standard texture analyser manufactured by Stable Microsystems, with few additional simple fittings and attachments. This design is capable of conducting friction/lubrication measurements over a wide range of sliding speed (0.01–40 mm/s) and at any chosen surface load. The set up is convenient to operate and easy to set controlled experimental conditions (e.g. sliding speed, surface load, temperature, etc). Syrup solutions and evaporated milk were used as examples of near-Newtonian and non-Newtonian fluids for feasibility tests and results were reliably reproducible. Friction coefficients obtained for syrup solutions were comparable to those reported in literature. Stribeck curves covering the boundary regime, mixed regime, and hydrodynamic regime can also be constructed. Our results demonstrate that this design provides a low-cost alternative for food lubrication studies. Details of experimental set up, its advantages and limitations were discussed in this paper.

1. Introduction

Eating is a dynamic process which involves size reduction (for solid and semi-solid food), saliva secretion and saliva mixing with the food, transportation of food particles, as well as the diffusion and release of taste and aroma compounds (Chen, 2009; Van der Bilt, 2012). The food texture sensation during an eating process is believed to be closely associated with the deformation behaviour of the food and is therefore governed by the mechanical or rheological properties of the food material. Based on this recognition, many instrumental methods have been proposed and proved to be efficient to assess and predict the textural properties of a food product. Extensive researches on instrumental characterisation of food textural properties have been well documented in the past few decades, from for example fluid viscosity studies (Cutler, Morris, & Taylor, 1983), to the viscoelasticity nature of semi-solid food (Foegeding et al., 2011), and the hardness of dry solid food (Kim et al., 2012). Fundamentals and applications of food rheology approach to food texture studies can be found in the well-known textbook by Bourne (2002), an excellent review by Van Vliet (1999) and recently by Stokes (2012a). Many of such instrumental methods have been applied successfully in food industry either for new product development or for quality control.

However, it has also been well-known that some other important textural features are hardly assessable by normal rheological approaches. These textural features include the sensory smoothness/roughness, the slipperiness, the creaminess, and etc. Such textural features were even completely excluded from the well-known texture profile analysis, the TPA, one of the most referred approaches of food texture studies (Friedman, Whitney, & Szczesniak, 1963). The reason of this exclusion is simply because that the detection and sensation of these textural properties has little relevance to the bulk phase deformation or bulk phase rheology. The sensation of these textural features is dominated by a thin layer rheology or the (relative) surface movement, a physical mechanism closely associated with "oral" tribology or "oral" lubrication. It is now commonly accepted that "oral" tribology could have an equally important role to food rheology in the sensation and perception of food texture. There could be a dynamic transition

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from rheology-dominated regime to tribology-dominated regime due to significantly reduced length-scale through different stages of oral processing (Chen & Stokes, 2012).

The possible relevance of tribology to eating and oral sensation has already been noticed many decades ago by Kokini, Kadane, and Cussler (1977), who showed that texture properties such as smoothness, slipperiness, and creaminess of fluid food had little relevance to their rheological behaviour but evidently linked to their lubrication behaviour. Unfortunately, importance of this finding was not fully recognised by food researchers. It was only in the past decade that interests of "oral" tribology research re-emerged, due to a well designed lubrication study of the sensory slipperiness of polysaccharide solutions conducted by a group of Unilever scientists (Malone, Appelqvest, & Norton, 2003). Since then, there have been many literature reports on "oral" tribology and food lubrication in relation to texture sensation of chocolates (Lee, Heuberger, Rousset, & Spencer, 2004), model hydrocolloids (De Vicente et al., 2006), food emulsions (Dresselhuis, Dd Hoog, Cohen Stuart, & van Aken, 2008). It has recently proposed that fatty/oily sensation and even the creaminess perception could be dominantly determined by tactile mechanism (Rolls, 2011) and oral lubrication could be the main contribute. Governing principles of "oral" tribology, in particular of their relevance to oral textural sensation, have been well discussed by Van Aken (2010) on modelling texture perception by soft epithelial surfaces and very recently by Stokes (2012b) on theories and practices of "oral" tribology study.

Experimental studies of tribology/lubrication require a very well controlled relative surface movement and a controlled surface load between the two "contacting" surfaces. Friction coefficient, defined as the ratio of the friction force to the surface load, is the key parameter showing the surface resistance against such a movement. For two surfaces in dry contact, the friction force shows a liner increase with the surface load. That is, the friction coefficient is a constant and its value depends solely on the surface properties (e.g. surface roughness, etc). In the case of a thin layer of fluid existing between the two moving surfaces (just like the tongue moving against the hard palate), the friction coefficient is a variable dependent on a number of operational parameters including the speed of surface movement, the surface load, as well as the viscosity of the fluid. There have been many experimental techniques available in recent years for food lubrication studies, including a Friction Tester, an Optical Tribological Configuration, a Mounted Tribological Device, a Tribology Cell, a Mini-Traction Machine (Prakash, Tan, & Chen, 2013). Most of these devices are commercially available, but the high cost of these equipments has been a big barrier for food researchers in establishing food tribology studies. Therefore, there is a need of a cheap alternative for reliable tribology studies. To this background, a commercial texture analyser has been adapted with some home-made accessories for friction/lubrication measurements. This experimental set up has a well controlled surface movement and surface load. Syrup solutions as near-Newtonian fluids and evaporated milk as a non-Newtonian fluid were used for feasibility tests. Initial tests showed that this experimental set up is reliable and easy to operate. It costs only a small fraction of a commercial tribometer and could be an ideal approach for food researchers to establish "oral" tribology studies at an affordable budget.

2. Experimental design and set up

A commercial texture analyser (Stable Microsystems, Surrey, UK) was used as the main device for this investigation. Exponent software (version 3.2) preloaded on the texture analyser was used for automatic data recording of the force, distance, and time. Additional accessories were designed and constructed in the faculty mechanical workshop, including a stainless steel base with a proper underneath water circulation for temperature control, a moving probe with three stainless steel balls in triangle arrangement, and an adapting connector to connect the moving ball probe to the load cell of the texture analyser. The texture analyser was laid to its side on a levelled work bench (see Fig. 1). The stainless steel base was screw-secured to the working-platform of the texture analyser. The round shaped lower (surface) platform was then placed firmly into the base via a locking mechanism (Fig. 1a and d). The lower platform itself has a hollow structure for water circulation to ensure appropriate temperature control. On the top of the platform was a shallow round trough of 85 mm in diameter and 4 mm in depth. A silicone elastomer of 1 mm thickness (NDA engineering Equipment Ltd, Kempston, UK) was placed in the trough as the lower substrate surface for friction tests (the blue surface shown in Fig. 1b). An appropriate amount of fluid sample (around 10 ml) was carefully transferred to the trough to give a full coverage of film surface. The moving probe (disc) is made of three stainless steel balls (5 mm in diameter) embedded (glued) into a steel base in a triangle arrangement (20 mm for each side) (Fig. 1c). It has its own weight of 27.8 g, giving a load of around 0.27 N. Various surface loads can be created by adding additional blocks of cupper on the top of the moving disc. Once the disc is dragged, the balls will be in sliding movement against the substrate surface. Both the upper and lower surfaces in this study were the same as those used in the previous study by De Vicente, Stokes, and Spikes (2006). According

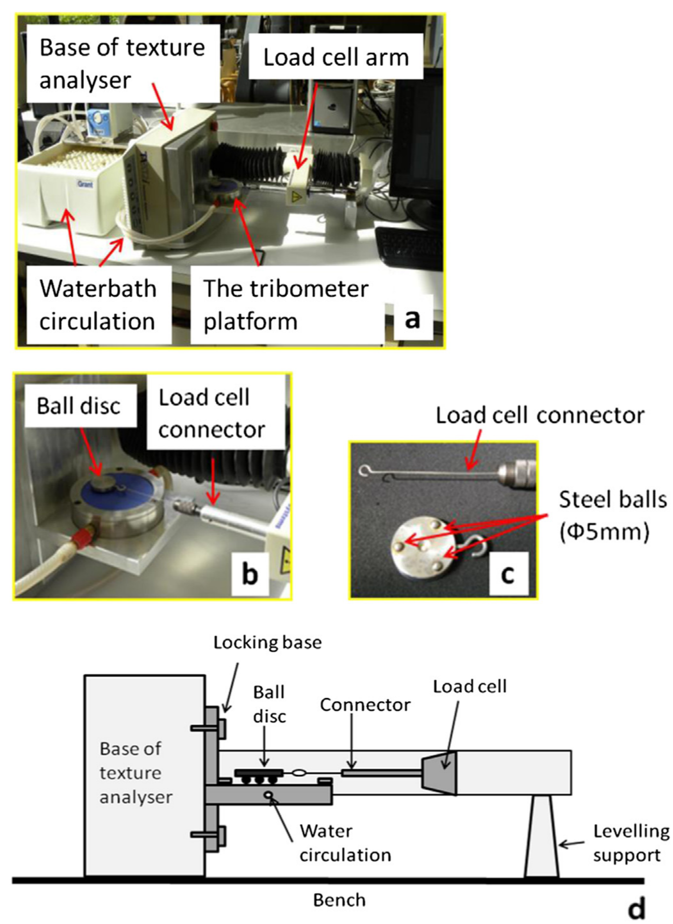

Fig. 1. Components design and experimental set up for lubrication studies. (a) A picture to show the layout of the experimental set up; (b) the ball disc and the base connected to the load cell; (c) the ball disc shown in its turnover position and the load cell connector the 5 mm diameter steel balls were firmly embedded into the moving disc of 30 mm diameter; and (d) an illustration of the experimental set up.