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Rheological characterisation of thickened milk components (protein, lactose and minerals)

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ABSTRACT

Thickened fluids are commonly used in the medical management of individuals who suffer swallowing difficulties (known as dysphagia). However, it is not always easy to obtain the correct consistency of thickened fluids. Variabilities can be due to thickening agents, solids content, and differences in dispersing medium. Thickened milk is a fluid that is commonly served for patients, but is one of the most complex fluids. This study examined the rheological characterisation of individual thickened milk components (protein, lactose and minerals) thickened with a commercial xanthan gum based thickener and investigated the effect of these components on the rheological behaviour of complete thickened milk. It was found that protein increased the final viscosity of the fluid but did not affect the dynamics of the thickening process. Conversely, mineral content significantly slowed down the thickening process, but only slightly increased the viscosity of the fluid. Lactose had no effect on either the dynamics of the thickening or on the final viscosity. This study confirms and explores the interactions between thickener and milk components in milk used for the medical and nutritional management of swallowing difficulties.

1. Introduction

Dysphagia is a medical condition where a person suffers from difficulty in swallowing (Logemann, 1998; Nicholson et al., 2008). Patients who suffer dysphagia are likely to reduce their dietary intake due to the condition which potentially results in malnutrition and dehydration. Other concerns may include aspiration pneumonia and asphyxiation (Althaus, 2002; Atherton et al., 2007). Dysphagia is a symptom of many conditions, such as premature birth, cerebral palsy, Alzheimer's disease and stroke (Althaus, 2002). Thus it affects individuals of all ages and has become a major issue throughout the world. The majority of patients are elderly due to illness, polypharmacy and weakened reserves (Cabre et al., 2010).

There are many ways to manage dysphagia, including feeding tubes, swallowing therapy and thickened fluids (Cichero et al., 2013; The FOOD Trial Collaboration, 2005; Althaus, 2002). Although a feeding tube can be used to provide nutrition while recovering the ability to swallow, it is not recommended for long-term use because it carries a great risk of complications (The FOOD Trial Collaboration, 2005). For long-term treatment, texture modifications of foods and fluids play a major role in clinicians' treatment (Hanson et al., 2012; Cichero et al., 2013). It has been reported that prescription of thickened fluids has become the most common recommendation made by clinicians as it is effective and easy to implement (Mills, 2008). Thickened fluids flow slowly, allowing for better oral and pharyngeal coordination and thus enhance safe swallowing (Reimers-Neils et al., 1994).

There are three levels of fluid thickness prescribed in Australia: Level 150 – Mildly Thick, Level 400 – Moderately Thick and Level 900 – Extremely Thick (Atherton et al., 2007). Ensuring thickened fluids have suitable rheological properties are an essential part of dysphagia management to promote safe swallowing. However, the patient may face serious consequences if the prescription is not followed (Atherton et al., 2007). Fluids that are too thin may be aspirated, potentially causing pneumonia. However, over-thickened fluids may become a choking risk, due to residue possibly inhaled from pharyngeal stasis. However, patients and carers have difficulty preparing thickened drinks to the correct thickness level. This is due to the heavy dependence of the viscosity of thickened fluids on a number of factors. These include: differences in thickening agent (Sopade et al., 2007, 2008a,b; Garcia et al., 2005), solids content of the liquid (Sopade et al., 2008a), and differences in dispersing medium (Sopade et al., 2007; Garcia et al., 2005; Nicholson et al., 2008) amongst other parameters.

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Previous work has focused on investigating the rheological properties of thickened milk and other dispersing media (Hadde et al., 2015; Sopade et al., 2008a). Thickened milk is a fluid that is commonly served to patients, as it offers fluids for hydration in addition to much needed protein and calcium (Claes et al., 2012; Barr et al., 2000). However, it is one of the most complex fluids, giving rise to higher equilibrium viscosity and requiring a much longer time to reach equilibrium than thickened water for a given amount of thickener using starch and xanthan gum based thickening agents (Garcia et al., 2008). If the manufacturer's instructions are followed, the fluid is more likely to have higher viscosity than it should have, whilst the slower thickening rate of the fluid means the patients are required to wait a longer time compared to other liquids prior to consuming the drinks. These behaviours are believed to be due to interactions between the thickeners and the various components in the milk, such as protein and lactose. The role of fat in the thickened milk has previously been studied and reported. It was reported that fat increases the equilibrium viscosity of thickened milk (Hadde et al., 2015). The objective of the current study was to:

(a) Rheologically characterise the process of thickening in milk.
(b) Investigate the effect of the milk components (protein, lactose and minerals) on the rheological behaviour of thickened milk.

2. Materials and methods

2.1. Materials

The liquids used in this study were local tap water (~120 mg/L) and commercial Devondale long-life skim milk. The commercial thickener product selected for analysis was Resource ThickenUp® Clear™ (Nestlé). The product is a xanthan gum based thickener and was chosen as it is commonly used in the healthcare industry in Australia.

Lactose powder, Milk Protein Concentrate (MPC) and calcium chloride were used to make up the milk component samples. Milk Protein Concentrate is a dairy protein containing both caseins and whey that have been extracted from the milk through membrane filtration (U.S. Dairy, n.d.). The MPC used in this experiment is MPC85, which contains 85% of milk protein together with other components such as lactose, fat and ash. Both lactose and MPC were obtained from the School of Agriculture & Food Sciences, The University of Queensland.

2.2. Sample preparation

The thickener manufacturer's guidelines were followed to prepare the samples, converting the scoop measures in the guidelines to masses of thickener, to ensure reproducibility of the results. The amount of thickener was added to reach Level 400 – moderately thick consistency (2.4% mass fraction) based on the manufacturer's guidelines. The thickener was added into an empty container and 100 mL of fluid was added into the container and stirred with a spoon until completely dissolved.

Four samples were initially prepared in this experiment: water + lactose, water + MPC, water + mineral and multicomponent (water + lactose + MPC + mineral). The amount of each milk component added was based on values observed in a composition analysis of skim milk (Table 1) which were measured by School of Agriculture & Food Science in the University of Queensland. Both water and long life skim milk were also tested by way of comparison.

Calcium chloride was used as the mineral component due to its tendency to dissociate when it is mixed with water. When calcium chloride is mixed with water, calcium chloride dissociates into positively charged Ca^{2+} cations and 2 negatively charged Cl^{-} anions, thus increasing the mineral concentration in the water. It was calculated that addition of 330 mg of calcium chloride in the water is equivalent to 120 mg of calcium ions. Similarly, addition of 3.8 g of MPC was equivalent to 3.3 g of protein in the water.

Prior to adding the thickener, the samples were stirred vigorously for more than 10 min using a magnetic stirrer to make sure the powders were completely dissolved. All test measurements were performed at 20 °C. Table 2 summarizes the composition of the samples.

Table 1
Characteristics of the commercial long-life milk.

Composition of skim milk per 100 mL	
Water (g)	91
Carbohydrates (g)[a]	5.2
Protein (g)[b]	3.3
Fat (g)[c]	0.1
Calcium (mg)[d]	120
Mass of thickener added (g)	2.1

[a] Measured by chromatogram.
[b] Measured by LECO CHN combustion analyser.
[c] Nutrition information of the product.
[d] Measured by varian ICP-OES.

2.3. Rheological tests

All tests were performed on a Thermo Scientific RheoScope 1 rheometer with HAAKE RheoWin Version 4 software. A cone and plate geometry was selected; diameter, 70 mm; angle, 1°, giving a fluid sample volume of 1.6 mL of fluid sample was placed on the RheoScope and test measurement was performed. In this experiment, the rheometer runs in small amplitude oscillatory strain mode, measuring a dynamic rather than a steady-state viscosity. This mode was chosen as we wished to observe changes in the thickened fluid properties without affecting their structure during the measurement. The strain amplitude for the oscillatory tests was chosen to be 0.1% as this lay within the linear viscoelastic region (LVR) for all of the fluids tested, where the rheological properties were not dependent on strain amplitude and thus the fluid structure remained undisturbed. It is expected that the dynamic viscosity measured in this experiment will be related to the steady-shear viscosity relevant for swallowing.

An oscillatory time sweep test was performed to observe the thickening dynamics of the material by measuring the change in the viscosity over a given time period. The tests were performed at the constant strain amplitude of 0.1% selected and a constant frequency of 50 rad/s. The tests were run for a total time of 50 min recording viscosity every 50 s. The measurements were repeated in duplicate. The temperature of the samples was maintained by a water circulator at 20 °C.

2.4. Statistical analysis

Two parameters were extracted in this experiment, η_{final} and $t_{90\%}$. η_{final} is the equilibrium dynamic viscosity (Pa s) of the fluid. $t_{90\%}$ is the time (minutes) required for the fluid to reach 90% of η_{final}, this is chosen to characterise the thickening rate of the fluid.

For the comparison of η_{final} and $t_{90\%}$ of the samples, analysis of variance (ANOVA) was carried out to determine statistical analysis difference ($p = 0.05$). Tukey's method was selected to categorize the differences. A p-value below 0.05 was regarded as statistically significant. The statistical analysis was done by Minitab 16 Statistical Software.