What Determines Foaming Ability of a Melt - Rheology or Surface Tension?

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ABSTRACT

The relative importance of extensional rheology and interfacial properties during proof of zein based dough as compared to wheat dough was determined. An analysis of the relative contribution to the pressure in a growing bubble was used as the basis[1]. The contribution from extensional rheology was shown to be considerably larger than that from interfacial properties both for the zein and the wheat based dough.

INTRODUCTION

There is an increased interest in alternatives to wheat for baking bread due to the high incidence of wheat gluten intolerance. Coeliac disease affects up to 1% of the population in the Western world. In southern Africa the interest depends on the need for decreasing the import of wheat which cannot be grown commercially due to climatic conditions. Other cereal proteins have therefore been investigated with the aim of baking porous, leavened bread, such as zein from maize and kafirin from sorghum[2, 3, 4, 5]. Zein and kafirin with the incorporation of starch can be formed into viscoelastic dough by kneading above the glass transition temperature. This non-wheat dough can then be baked into porous bread by conventional baking procedures.

There is a controversy in literature on the relative importance of extensional rheological properties and interfacial properties[6, 7] for bubble stabilization in dough. For wheat dough, both schools stress the importance of glutenin, but from different viewpoints. Similarly there are two main models describing the unique viscoelastic properties of wheat dough, the flexible polymer type "loop-and-train" model[8] and the particulate "hyper aggregation model" [9]. Sroan et al. have proposed a model containing both mechanisms[10, 11]. Grenier et al. determined the pressure in a growing bubble in dough using miniaturized pressure transducers[1]. They also introduced a model describing the pressure in terms of the hydrostatic pressure as well as the contribution from the interfacial properties and rheology.

The aim of the present study was to express the relative importance of extensional rheology and interfacial properties in terms of the pressure components in the Grenier[1] analysis. These components were calculated from measured data of surface tension and extensional viscosity for a zein based dough as compared to a wheat gluten dough.

THEORY

A model for the total gas pressure inside a growing bubble P(t) as a function of the proving time was expressed as[1]

$$P_{total\,pressure\,(t)} = P_{hydrostatic\,(t)} + P_{surface\,tension\,(t)} + P_{rheology\,(t)} \qquad (1)$$

where the respective terms denote the relative contribution from the weight of the dough (hydrostatic pressure term) the surface tension and the extensional rheology. The terms are deduced as follows

$$P_{hydrostatic}(t) = \varrho_{(t)}\, g\, R_{d(t)} \tag{2}$$

where ρ is the dough density, g the gravity of Earth and R_d the radius of the dough. The surface tension term is deduced from the Young-Laplace equation as

$$P_{surface\ tension}(t) = \frac{2\gamma}{R_{(t)}} \tag{3}$$

where γ is the surface tension of the dough. Assuming Newtonian dough with viscosity η the rheology term was described as

$$P_{rheology}(t) = 4\eta\, \frac{1}{R_{(t)}}\, \frac{dR_{(t)}}{dt} \tag{4}$$

MATERIALS AND METHODS

Zein and corn starch were purchased from Sigma-Aldrich (Stockholm, Sweden).

The mixing was performed using a modified, heated meat grinder at 40 °C. The mixing time was set as 4 minutes in order to obtain homogeneous dough.

The foaming was performed by baking at 140 °C for 10 min between heated plates.

Hyperbolic Contraction Flow[12] was performed to determine the uniaxial extensional viscosity as described Oom[3] and others[5].

Surface tension measurements were performed with a telescopic contact angle goniometer (model 50-00 / 100-00 (Ramé-hart Instrument Co, Succasunna, USA) replacing the microscope section with a Nikon D90 Digital Camera (Nikon Corporation, Tokyo, Japan).

RESULTS AND DISCUSSIONS

The aim of this study was to compare a zein based dough to a wheat based dough regarding the relative importance of extensional rheology and surface tension for the respective dough. The ratio of their respective contribution to the total pressure in a growing bubble can be expressed by combining Eqs. 3 and 4 as

$$\frac{P_{rheology}}{P_{surface\ tension}} = \frac{2\eta}{\gamma}\frac{dR_{(t)}}{dt} \tag{5}$$

The growth of a bubble in the dough was qualitatively comparable to the previously published data for proof of wheat dough as studied by confocal laser scanning microscopy. These data for R(t) was therefore used[1] which can be expressed as in Fig. 1.

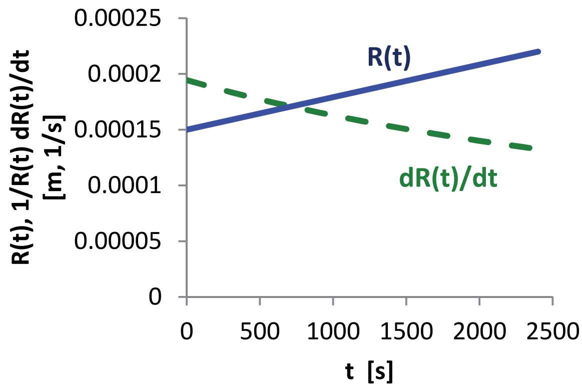

Figure 1. $R_{(t)}$ and $dR_{(t)}/dt$ for a typical bubble in a dough during proof[1].

The surface tension and extensional rheology is summarized in Table 1 together with the resulting ratio of $P_{rheology}/P_{surface\ tension}$ calculated using Eq. 5.

Table 1. Table of measured extensional viscosity, η_e and surface tension, γ, and calculated pressure components for a growing bubble in dough during proof.

	Zein dough	**Wheat dough**[1]
γ [N/m]	0.062	0.034
η_e [MPas]	1.70	1.20
$P_{rheolog}$ [Pa]	1 300	930
$P_{surface\ tension}$[Pa]	830	450
$\frac{P_{rheology}}{P_{surface\ tension}}$	1.6	2.1

Table 1 shows that the relative contribution from the extensional rheology is considerably larger than that from surface tension for both the zein and the wheat dough. Zein is more hydrophobic than gluten which should increase the effect of the surface tension, but it also has higher extensional viscosity which somewhat counteracts the effect of hydrophobicity.

One limitation of the model used is that it assumes the dough to be Newtonian, which it clearly is not. However, extension rates during proof are low, typically in the order of 10^{-4} s^{-1} which makes the assumption more reasonable. For faster foaming processes such as steam expansion the analysis needs to be revised to accommodate the non-Newtonian behavior and temperature dependence of the dough.

CONCLUSIONS

Assuming slow bubble growth during foaming, such as during proof of dough, the effect of extensional rheology is considerably larger than that caused by interfacial properties.

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