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Impact on dough aeration of pressure change during mixing

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ABSTRACT

This study aimed to provide a better understanding of the impact on dough aeration of pressure change during dough mixing with a spiral dough mixer with the possibility of controlling the temperature and the overhead pressure from −960 mbar to +500 mbar during mixing. The objectives were to understand the effect of pressure on dough during kneading in order to optimize dough kneading conditions. The well-known experimental strategy was to knead with overpressure to incorporate gas into the dough and maximize dough aeration then to subdivide the gas bubbles introduced in the previous step by applying a vacuum in the mixer's overhead. The results showed that dough aeration was proportional to the number of rotations of the spiral. The time to reach equilibrium was longer for a larger pressure drop. The kinetics of disentrainment were slower with the highest pressure drop.

1. Introduction

Dough aeration is very important in the bread-making process because it contributes to oxidation reactions and initiates proving by entrapping air bubbles. Bread aeration (or specific volume) is a criterion of quality and the desired bubble distribution depends of the type of bread (e.g. a fine and homogeneous alveolation for a sliced bread or large bubbles for a French baguette). In contrast, for other applications, such as pizza, dough has, to be degassed. Thus controlling dough aeration is essential to obtain good product quality. Dough aeration occurs during kneading, the first step of the bread-making process during which, the kneading spiral agitator rotation combines the dry and liquid ingredients to obtain a homogeneous dough. On one hand, this mixing makes several biochemical reactions occur, between the ingredients themselves and between the ingredients and air (Stauffer, 2007; Haegens, 2014), which contributes to the formation of the gluten network. On the other hand, the kneading spiral agitator movement entraps air bubbles.

Gluten network establishment gives to the dough its rheological properties. During mixing, in oxidizing environment, sulfhydryl SH sites are interchanged into disulphides bonds SS which link glutenins together (Dobraszczyk et al., 2001). This network of proteins makes the wheat flour dough viscoelastic that retains gas bubbles whereas other flour types dough (Hoseney and Rogers, 1990).

The establishment of the gluten network during kneading results in an increase in dough viscosity and, in turn, a warming of the dough. Part of the mechanical energy due to the mixer spiral agitator rotation is transformed into heat by viscous dissipation, resulting in a temperature increase. Heat is transferred to the dough and to the atmosphere (Shehzad et al., 2012). Another part of this energy helps to develop the gluten network (Tanaka and Bushuk, 1973) which gives the dough its rheological properties, that contributes to its gas retention capacity. During kneading, as the gluten network is forming, the dough becomes increasingly resistant so that the power needed to maintain the spiral agitator rotation speed increases until the maximal cohesion of the gluten network is achieved. Then, the spiral agitator power decreases: the amount of gluten network formed becomes lower than the amount destroyed by the spiral agitator. The maximal power level and the corresponding time (t_{PEAK}) are important data to control gluten network formation. When dough is overmixed (dough breakdown), it tends to become sticky. It also loses its viscoelastic properties. The optimal mixing time does not necessarily correspond to the time for which the dough has the maximum shear resistance (t_{PEAK}). Usually, by observing and manipulating the dough, a traditional baker detects that kneading ends slightly before t_{PEAK} (Fig. 1). This can be supported by the fact that during the rest period (between the end of kneading and dough shaping), the gluten network continues to form (Hoseney, 1994). Moreover, after resting, the

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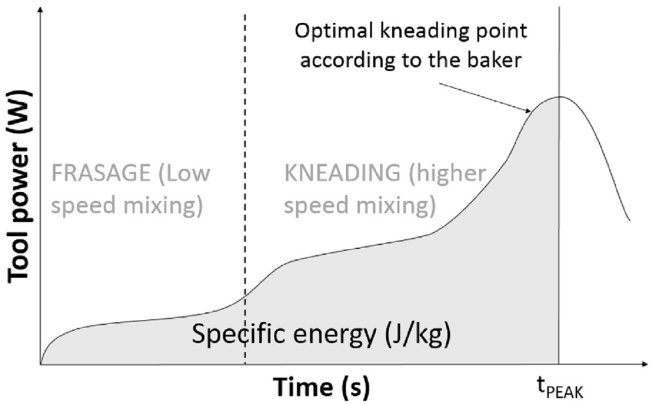

Fig. 1. Evolution of spiral agitator power consumed during mixing.

dough is shaped before fermentation, which adds mechanical stress that may contribute to gluten network formation.

1.1. Dough aeration

The kneading spiral agitator rotation exerts compression, elongation and shearing on dough. Overall, it stretches the dough batch, which come into contact again later, entrapping air bubbles and contributing to dough structuring as described by Baker and Mize (1941, 1946) and quantified by Potus and Nicolas (2010). The spiral agitator movement has two effects: firstly, stretching the dough batch leads to bubbles break-up and disentrainment (Campbell et al., 1998;Campbell, 2003; Martin, 2004), then, introducing gas bubbles into the dough by folding up the stretched dough. Campbell and Shah (1999) and Chin et al. (2004) established a mathematical balance model to associate a disentrainment coefficient k and a volumetric entrainment rate ν. During mixing, the pressure modulation changes the amount of air in the mixer and the balance between the pressure in dough bubbles and the pressure in the mixer. The overpressure in the mixer's head increases the amount of entrapped gas in the dough. Applying a vacuum during mixing has two effects: firstly, the entrapped gas bubbles grow in size and are subdivided by the spiral agitator; secondly, the disentrainment of air will occurs because of the pressure difference between the gas bubbles and the mixer's head and because of the micro-porosity of the dough (Campbell et al., 1998). In industry, doughs that will be fermented are usually mixed at low speed at atmospheric pressure (P_{atm}) then at higher speed under overpressure to incorporate more gas into the dough before a fast final step under partial vacuum to enlarge and break the gas bubbles (Fig. 2). Modulating the pressure during mixing in presence of

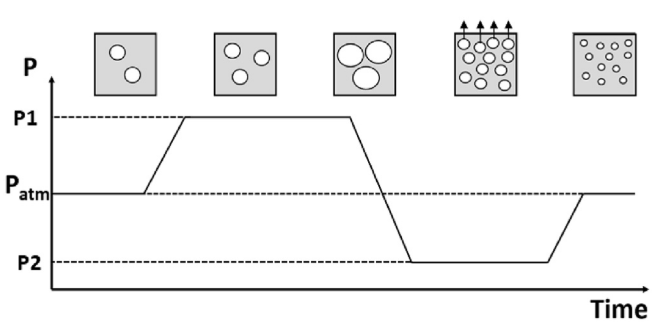

Fig. 2. Schematic representation of the effect of pressure evolution during mixing with an over pressure and vacuum that could be applied to sliced bread to promote dough aeration during mixing.

ascorbic acid optimizes bread volume. The pressure increase brings more oxygen and with ascorbic acid oxidase, an enzyme naturally present in the wheat flour, the ascorbic acid is converted to the dehydro form. This form takes part in the oxidation reactions such as the thiols-disulphides SH/SS interchange which make the gluten network more elastic, contributes to the gas retention and so increases the bread volume (Sahi, 2014). Partial vacuum at the end of mixing leads to a finer cell distribution in bread crumb (APV Corporation Ltd, 1992; Cauvin, 1994).

1.2. Balance model

The model associating the disentrainment coefficient k and the volumetric entrainment rate ν during kneading was made by Campbell and Shah (1999) and Chin et al. (2004).

This model is based on a mass balance of air

$$\mathbf{\frac{dm}{dt} = \dot{m}_i\text{-}\dot{m}_o} \tag{1}$$

Hypothesis:

- The entrainment of air into dough is constant:

$$\mathbf{\dot{m}_i = \nu\frac{PM}{RT}} \tag{2}$$

were ν is the volumetric entrainment rate $\left[\frac{m^3\ air}{m^3\ gas\ \ free\ dough\ .\ \ second}\right]$

- The disentrainment of air is proportional to the mass of gas trapped in dough:

$$\mathbf{\dot{m}_o = km_a = k\frac{PVM}{RT}} \tag{3}$$

were k is the disentrainment coefficient of gas. $\left[\frac{kg\ gas\ outgoing}{kg\ gas\ in\ dough.second}\right]$

By substituting equations (2) and (3) into equation (1):

$$\mathbf{\frac{dm}{dt} = \frac{PM}{RT}(\nu - kV)} \tag{4}$$

The previous equation expressed in volume yields:

$$\mathbf{\frac{dV}{dt} = (\nu - kV)} \tag{5}$$

This is a first order differential equation. The solution is:

$$\mathbf{V(t) = \frac{\nu}{k} + \left(V_0 - \frac{\nu}{k}\right)e^{-kt}} \tag{6}$$

The dough density can be used to calculate the volumetric air content at atmospheric pressure V_{atm} $\left[\frac{m^3\ gas}{m^3\ gas\ free\ dough}\right]$ which can be linked to the volumetric air content at mixer pressure using the ideal gas law:

$$\mathbf{V = \frac{P_{atm}}{P}V_{atm}} \tag{7}$$

Based on the mathematical model of Campbell and Shah (1999) and Chin et al. (2004), the disentrainment coefficient k can be calculated as follow:

$$\mathbf{\frac{V_{atm}(t) - V_{atm_\infty}}{V_{atm_0} - V_{atm_\infty}} = V^*_{atm}(t) = e^{-kt}} \tag{8}$$

To quantify the amount of air that leaves the dough, the disentrainment coefficient can be determined in 2 different ways: