Journal of Food Engineering 199 (2017) 93–99

Contents lists available at ScienceDirect

Journal of Food Engineering

journal homepage: www.elsevier.com/locate/jfoodeng

Fuzzy logic based process control strategy for effective sheeting of wheat dough in small and medium-sized enterprises

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ARTICLE INFO

Article history:
Received 1 June 2016
Received in revised form
12 December 2016
Accepted 17 December 2016
Available online 19 December 2016

Keywords:
Dough sheeting
Process control
Surface cracks
Rheological properties
Fuzzy logic

ABSTRACT

One of the prime aspects in small and medium-sized baking enterprises (SMEs) is to control and improve the dough sheeting process. Dough sheeting is an important phase in producing various baked products such as breads, pastries, pizza etc. This is one of the key feature that helps to achieve optimized timing and product quality. The deployment of a fuzzy control system is one of the feasible option when complexity of the process is high. The fuzzy control system (program) developed in this research can regulate the roll gaps based on the input parameters such as dough thickness, rheological measurements and surface cracks. The results demonstrated that by the implementation of a fuzzy system an optimized dough sheeting method is achieved. On comparison of the results with a non-fuzzy system, the dough was rolled in less time without making any compromise with the dough quality.

1. Introduction

Even for the small to medium sized industry, handling the flow of process information with an automated system is crucial not only to control the process, but to ensure optimum product quality and productivity. Computerized controls can be used to upgrade existing equipment as well as for new facilities. Digital or computer-based process controls optimize process and equipment efficiency (Mittel, 1997).

In the baking industry achieving quality products consistently must be the goal of any baker striving to improve the business. Their greatest potential lies with the integration of bakery processes with computing environments, systems and techniques (Young, 2007). The use of advanced control techniques such as model-based predictive controllers, intelligent and software sensors, neuro-fuzzy control and expert systems lead to reduced costs, increased quality and improved safety along with an expectation to improve process profitability and business competitiveness (Linko & Linko, 1998). One of the well-known processes that helps in decision making based on human operator's experience and measured process variables is fuzzy logic (Zhang & Litchfield, 1993). Some applications of fuzzy logic in baking industry are given in Table 1.

The aim of the proposed work is to establish a fuzzy control system considering parameters such as dough rheology, thickness and surface cracks for designing efficient rolling process of wheat dough particularly in SMEs. The rheology of wheat dough is considered crucial in the successful manufacturing of bakery products (Faridi & Faubion, 1990). It plays an important role in determining the processing behavior and quality of baked products (Bloksma, 1990). Rheological principles and theory can be used as an aid in process control and design (Dobraszczyk & Morgenstern, 2003). In automated bakeries, knowledge of dough viscosity plays an important role in production control and equipment design. Dough viscosity may relate to the quality of the baked product and may control that quality in some instances (Sharma et al., 1993). In addition to dough rheology, dough thickness and surface cracks are also prominent parameters affecting the baked product quality (Quail et al., 1990; Mahadevappa et al., 2015). Moreover controlling dough sheeting processes has been a long standing challenge in the food industry. Due to the difficulties in controlling the dough thickness on the line, there has been issues in maintaining a consistent rate of production (Chakrabati-Bell et al., 2010).

Efficiency of the sheeting process is achieved by using the output parameters provided by the fuzzy control system such as addition of flour and the roll gap (using which the next rolling step is adjusted). Addition of flour is an important aspect in reducing the stickiness of the dough. Stickiness is a common hindrance

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http://dx.doi.org/10.1016/j.jfoodeng.2016.12.013
0260-8774/

Table 1
Applications of fuzzy logic in baking industry.

SN	Application	Reference
1.	Quality evaluation of biscuit during baking	(Perrot et al., 1996)
2.	Bread baking process control	(Kim and Cho, 1997)
3.	Cookie baking	(Perrot et al., 2000)
4.	Consumer ratings on chocolate chip cookies	(Davidson et al., 2001)
5.	Controlling the browning process	(Ioannou et al., 2004)
6.	Prediction of chapati making quality from different Indian wheat varieties	(Gangadharappa and Prabhasankar, 2011)
7.	A sensory study for analysis of acceptability of millet-based dough and breads	(Singh et al., 2012)
8.	Effective control of temperature in the bread baking chamber	(Finaev et al., 2015)

interfering in the production process, causing considerable wastage and contamination of equipment (Dobraszczyk, 1997).

The results of this research is an addendum to the inline measurement technique used to assess the quality of the wheat dough during sheeting process (Mahadevappa et al., 2015).

2. Materials

Two types of wheat dough are considered for this study, namely ciabatta (dough with yeast) and puff pastry (dough without yeast). Two different types of wheat flours commercially known as “Brema flour” and “Keks flour” are used to prepare the dough samples along with different additives such as oxygen enriched water (80–115 ppm), tap water (2–7 ppm) and cysteine (0.001%, 0.005%, 0.01%). The wheat flour is supplied by Bremer Rolandmühle, Erling GmbH und Co KG, Bremen. The dough is prepared using the recipe as shown in Table 2.

In this research the spiral kneader from the company WP Kemper, Germany and the sheeting machine from Rondo Burgdorf AG, Switzerland are used. The plate-plate rheometer from Anton Paar MCR 301, Ostfildern-Scharnhausen, Germany is used to carry out the rheological measurements.

For every trial 15 kg dough is mixed using the spiral kneader. The dough is manually divided into approximately 2.5 kg portions. Each portion is sheeted within a roll gap range from 45 mm to 5 mm using two sheeting programs (Table 3). Program 1 with eight steps, corresponds to be a slow and gentle program similar to the one often used in small and medium sized bakeries. This program rolls the dough in a gentle manner using small increments of roll gaps and with least possible stress reduction. Program 2 with five steps is comparatively faster, due to the lesser number of rolling steps. In this case, the dough experiences significantly greater stress. These two are the basic programs using which the fuzzy system optimizes a program of its own.

Table 2
Dough recipe for ciabatta and puff pastry.

Ingredient	Ciabatta (%)	Puff pastry (%)
Flour	100	100
Water	56	50
Salt	1.2	2
Sugar	10	2
Yeast	6	–
Sunflower oil	2	–
Fat	–	5

3. Implementation of the fuzzy system

A typical fuzzy system operates on input parameters, applies the defined rules and finally provides the output. Keeping the same framework, two fuzzy system variations - fuzzy variation 1 (FV 1) and fuzzy variation 2 (FV 2) are developed in the present research (Fig. 1).

In FV 1, the dough thickness and surface cracks (obtained using inline measurement technique - refer sections 4.1 and 4.2) are selected as input parameters. FV 1 evaluates these input parameters against a set of defined rules in order to select the most efficient output parameters, which form the input for the next rolling step. The addition of flour and roll gap are the two output parameters.

FV 2 is similar to FV 1 except for the fact that it considers rheological measurements (offline measurements – refer section 4.3) as an extra input parameter.

The rules for these two variations of fuzzy system are based upon the findings of the image processing and rheological measurements (Mahadevappa et al., 2015). They are programmed using the software MATLAB (Fuzzy Logic Toolbox).

The complete outlook of the setup for the dough sheeting process which is a combination of the current research and the setup explained in the paper by (Mahadevappa et al., 2015) is depicted in Fig. 2.

4. Input parameters

Decision making in fuzzy logic is based upon the input parameters. The input parameters used in this research are dough thickness, surface cracks and rheological measurements.

4.1. Dough thickness

Dough thickness is the thickness of the dough obtained when sheeted between two rollers with a specific roll gap (distance between the two rollers).

The fuzzy system should output a suitable rolling profile for every dough being rolled. The belt speed of the sheeting machine is 26.4 cm/s. The first rolling step of 45 mm as well as the final thickness of 5 mm is achieved by default. The intermediate rolling steps are oriented between a gentle and a consistently stressful program depending on the nature of the dough. Based on the roll gap, there are four membership functions for the dough thickness input: thick, medium, thin and final thickness (Table 4). The dough thickness input is in the range of 5 mm–45 mm.

Table 3
Representation of the basic predefined rolling programs.

Sheeting program	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7	Step 8
Program 1 (P1)	45 mm	35 mm	25 mm	15 mm	10 mm	8 mm	6 mm	5 mm
Program 2 (P2)	45 mm	30 mm	15 mm	5 mm	5 mm			