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New insight into pasta cooking: the continuous cooking procedure in professional appliances

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New insight into pasta cooking: the continuous cooking procedure in professional appliances

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I declare that my Ph.D. thesis has been amended to address all the Referee’s comments.

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TABLE OF CONTENTS

PREFACE

Nowadays, in the product development process, engineers and kitchen operators run cooking appliance development and use at different steps, using diverse tools, languages and perspectives.

During continuous cooking in pasta cookers, the same cooking water is used for hours to promptly serve the consumers. Solid concentration results in intense foam formation that leads to overflow. Water, energy, time consumption, cooking water viscosity and turbidity increase as well as cooked pasta quality changes are reported by kitchen operators, and thus reflected in industrial needs to the engineers.

This Ph.D. thesis aimed at proposing a new approach for food scientists in the food service sector to fulfil the disciplinary gap between engineers and kitchen operators. To this purpose, the continuous cooking procedure in professional appliances was chosen as study case. The effect of the continuous cooking on physical and chemical properties of pasta and cooking water was investigated by simulating the procedure on laboratory scale. Selected unconventional technologies such as ultrasounds and high pressure homogenization were applied on laboratory scale to retain fresh-like cooking water properties. An ultrasonic batch system and conventional strategies, such as the power rating management, were investigated on industrial scale in the attempt to tackle continuous cooking procedure issues.

This study provides original insights into pasta cooking by studying the continuous cooking procedure in professional appliances. Furthermore, the gap is fulfilled by a food science-based approach, both on laboratory and industrial scale. This thesis opens up new scenarios for appliance development, reflecting on how to approach the development in the manufacture and the use in the professional kitchen.

Chapter

1

General introduction

ELECTROLUX PROFESSIONAL

Electrolux Professional is the branch of the Electrolux Group, and the only company in the world that is able to provide both premium food-service equipment and laundry solutions. Electrolux Professional represents the 7% of the entire production of Electrolux Group (AB Electrolux, 2018). The production of Electrolux Professional kitchen appliances has strong roots within the Italian industry of Zanussi, in Pordenone. Founded as a division of the Zanussi household appliances in 1959, it was acquired by Electrolux group in 1984, so then, food service equipment was recognized in the global market as Electrolux Professional and Zanussi Professional appliances. Founded in Sweden in 1919 by entrepreneur Axel Wenner-Gren, in 2019 Electrolux turned 100 years.

Electrolux Professional fulfills the business-to-business[1] (B2B) Horeca[2] market by providing a comprehensive range of solutions to store, prepare, cook, serve food, and to clean the tools employed in the food service. Particularly, Electrolux Food Service equipment is tailored for different types of professional kitchens (from Michelen starred restaurants, to pubs and bars, from hospitals, schools and military canteens to Quick Service Restaurants). Products contribute to combine excellent results, productivity and hygiene with low energy consumption and operating costs. The different appliances employed in the food service industry could be divided in six main categories: modular cooking, ovens, dynamic preparation, refrigeration, dishwashing, and other appliances. Some of these are shown in Figure 1.1. The modular cooking area offers the complete flexibility of feature combinations: electric, gas and induction modular functional elements, fryers, pasta cookers, fry tops and grills, and storage elements. The modular cooking lines 900XP and 700XP are usually present in high productivity kitchens and aim at assuring the best cooking results in terms of taste, colour evenness and texture, as well as nutritional value preservation, and a consistent reduction of cooking time and energy consumption.

The user of professional appliances and the consumer in the establishment drive the appliance choice, in terms of model, category and brand. So, cooking in the professional industry involves a delicate negotiation among users, (servers), and consumers, with each having demands, constraints, and rights.

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[1] Business-to-business marketing involves the commercial transaction of a company's product or service to another company (Temporal, 2005).

[2] From international Union of National Associations of Hotel, Restaurant, and Café Keepers, HORECA is an abbreviation used in Europe to designate the food service Industry Market (Restaurants, Hotels, Bars And Cafés, Supermarkets, Hospitals And Care Homes, Business, Transport & Industry, Commercial Laundries, Self-Services Laundries) (Eurostat, 2005).

These have to be translated into engineering metrics by Research and Development[3] (R&D) engineers in the manufacturing while future needs have to be pre-empted.

Figure 1.1. Electrolux Professional Food Service products.

The engineer's perspective

Catering is a complex system involving both people and equipment (e.g. professional appliances) in the preparation and serving of food and, in the broader sense, is the provision of food and beverages away from home (Davis et al., 1998). Food service industry serves billions of meals every year. Reliable and accurate data on the size of the industry are difficult to obtain but by way of example, total global spending is expected to grow 13% over the next five years, producing USD359 billion in incremental value. The food service industry employs 14 million people in the USA and 8 million in Europe (Euromonitor International, 2011; Gössling et al., 2011). The B2B market is highly fragmented in terms of customers' needs and geographic areas. The US market is characterized by the presence of large restaurant chains, while the European one is mostly dominated by smaller independent establishments (De Toni, 2016; Hague & Harrison, 2019). In general, increasing need for modern kitchen amenities and shift in kitchen operator preference for modular kitchen is boosting the demand for specific appliances. Smart kitchens and various innovations in the industry are helping the kitchens in

[3] Research and development refer to the activities company undertakes to innovate and introduce new products and services.

restaurants and hotels become efficient and manageable (Grand View Research, 2019; Paananen & Seppänen, 2013). The development of professional appliances has been entrusted to engineers, whose role is more and more important in the appliance development at manufacturing. Shifting consumer preferences from conventional to technologically advanced products is enabling manufacturers to offer innovative kitchen appliances. This increases the key role of engineering but highlights also the lack of a food science multidisciplinary approach when cooking appliances have to be developed.

In the product development process within the R&D department, the project status is evaluated based on time, benefits and costs. Furthermore, the technical maturity following the Technology Readiness Levels (TRLs)[4] concept is often assessed. The technical maturity of the project is subdivided into levels that can be named as follows:

1. Basic principles observed;
2. Technology concept formulated;
3. Experimental proof of concept;
4. Technology validated in lab;
5. Technology validated in relevant environment;
6. Technology demonstrated in relevant environment;
7. System prototype demonstration in operational environment;
8. System complete and qualified;
9. Actual system proven in operational environment.

At each update, the technology readiness assessment is also presented to the steering committee for approval to move on with the project (Mankins, 2009).

The kitchen operator's perspective

The same appliance is intended to be used by multiple users in terms of experience and skills. In the fast food chains, workers are often less skilled and experienced, and their role is usually in a high rotation system. Therefore, the appliance should be operated as much quickly, automatically and standardized as possible. In the case of star restaurants, the appliance should also be flexible maximizing the chef's creativity by minimizing repetitive tasks and stress inputs.

From the user perspective, all work is temporally structured. In the conventional catering approach of "cook and serve", food is cooked and immediately served to consumers with all stages of food preparation occurring

[4] In the mid-1970s, the National Aeronautics and Space Administration (NASA) introduced the concept of TRLs as a discipline- independent, program figure of merit to allow more effective assessment of, and communication regarding the maturity of new technologies, especially among sometimes diverse organizations (Mankins, 2009).

in a few hours before the food is served and consumed. This is typically the case of restaurants and canteens. The food is distributed at a temperature of 65 °C and the consumption should occur within 2 h after cooking (Ciappellano, 2009; EpiCentro, 2012). Therefore, organization in the kitchen staff and temporality are intimately connected. For a kitchen to run efficiently, schedules must be meshed, and work products must be generated at a determined rate. Within the serving hours, the irregular and unpredictable demand for dishes gives the kitchen operators the power and pressure within the kitchen. The role of professional appliances in guaranteeing the performances and the wellbeing of workers is particularly evident when the kitchen is loaded to capacity. When more consumers than expected arrive (or when something goes wrong), the kitchen falls behind in the duration of preparing dishes, then the consumers do not get their food on time and the establishment increases the risk of client loss.

Another important point from the food service operators is related to the need to economize on energy and labor costs (Reeve, Creed, & Pierson, 1999). The average daily energy usage for the establishment could be around 294 kW/h. The total average electricity usage attributed to cooking appliances is around 60% of the kitchen (Mudie et al., 2014). One clear approach to energy reduction is through better product design and this has been the focus of UK and EU policy via the Eco-design of Energy using Products Directive (European Commission, 2011), but still a lot has to be done.

The kitchen is a noisy environment and operators are frequently exposed to hot pans or fryers/pasta cookers, increasing the risk of burns, and slips and falls due to moisture on kitchen floors (Figure 1.2). The type of appliances and tools and the high level of activity and pressure in kitchens during serving hours increase the risk of accidents (HSE, 2015; ILO, 2019). Jeong (2015) reported the distribution of work time and injured persons according to the relevant cooking process in 100 commercial restaurants. The percentage of heated cooking was the highest at 18% and the associated percentage distribution of injured persons was 21%. Safer appliances and procedures are asked to be developed to reduce occupational accidents in the food service.

Figure 1.2. Examples of professional kitchen environment.

The consumer's perspective

Food quality, service environment and service performance are the three main criteria used by the consumers to evaluate the establishment. These factors need always to be considered and assessed in their entireness. Professional appliances play a critical role on at least two of these factors, all of them in the case of open kitchens. In establishments with open kitchen, service environment includes the appliances and the whole kitchen, so design aspects are crucial. Compared to the engineer's perspective in the manufacturing plant, in the establishment the consumer is involved in the creation of the service that is consumed at the point of production with little or no time (e.g. self-service) delay between production and food service. Therefore, there is little if no time for the quality control by the kitchen operator, thus the appliance plays fundamental role in guaranteeing always the same food quality. Time, or lack of time, can affect the service performance and so the eating out experience of consumers in a number of ways. Time concept is related to mealtime during the day, time available to consume a meal and waiting time to get served. The effect of making people wait has been demonstrated to result in lower acceptability ratings of the food (Davis & Heineke, 1998; Hul, Dube, & Chebat, 1997).

THE CASE STUDY OF PASTA COOKING IN PASTA COOKERS

Pasta cookers

Back in the 70s, the call for mass production of commercial solutions prompt the evolution of modular lines of professional appliances, in which pasta cooker represents a module. Pasta cookers can be either gas or electric, smaller as in the 700XP line or bigger as in the 900XP line of Electrolux Professional appliances. Pasta cookers resemble a deep fat fryer but are filled with water instead of oil, while use similar stainless-steel enclosures (Birchfield & Birchfield JR, 2007). Engineers have added features, such as: a water connection for ease of filling and maintaining the water levels in the well, a top drain to skim off foam, and are frequently accompanied by a cold water rinse tank to potentially stop the pasta from overcooking. Pasta cookers can employ many of the same control systems as the more advanced fryers, including automatic lift baskets to lower and raise the baskets so that cooking time is controlled, integrated timers, and solid state controls (Spoor, Zabrowski, & Mills, 2014). As an individual appliance in the kitchen, pasta cookers can be very energy intensive. This is related to the need of heating and holding large volumes of water at high temperatures during the serving hours, but also to the procedure with which the appliance is used: the continuous cooking.

The pasta cooker is filled with fresh water and when the boiling point is reached, pasta is manually added and then removed when it is cooked, while in industrial continuous pasta cookers it automatically enters. The same water batch is used many times (up to 13 and 50 in food service and industry, respectively) to cook pasta (Korzeniowska, Korzeniowski, Defrancisci, & Hoskins, 2005). This procedure is named continuous cooking. It allows to promptly satisfy the consumer's order and guarantee an efficient use of energy and water in the kitchen compared to using a pot or emptying the appliance for cooking with fresh water as on domestic scale. However, during the continuous cooking process, a foam layer forms upon cooking causing the water to go into the overflow drain. Thus, kitchen operators must continuously release water and replace it by an equal amount of fresh water that has to be heated, with increased time and energy consumption and thus operating costs for the establishment. In addition, foam formation results in safety issues and depletion of work quality conditions and performance for the kitchen operators. Ultimately, the continuous cooking procedure may change cooking water and final product properties, as empirically reported, that dissatisfy the consumers and therefore again the kitchen operators. There is the increasing need for understanding and finding optimization strategies able to avoid such phenomenon.

Pasta cooking

Pasta is a staple food in much of the world. Versatility, ease of transportation, handling, cooking properties, long shelf-life, diversity of form, high digestibility, good nutritional qualities and relatively low cost, make pasta one of the favourite foods by consumers (Martinez et al., 2007; Rakhesh, Fellows, & Sissons, 2015; Tudorică, Kuri, & Brennan, 2002). Durum wheat (Triticum turgidum L. var. durum) is the cereal of choice for pasta production because of the peculiar properties of its proteins and gluten, as well as its yellow pigment content (Martinez et al., 2007). Pasta is traditionally cooked in an excess of fresh water (the recommended pasta/water ratio is 1/10) at boiling temperature (Cocci et al., 2008). As more extensively described in Chapter 2 and 3, during the cooking of pasta, high temperature and high moisture conditions lead to progressive hydration and component solubilisation, resulting in major structural changes, i.e. protein (further) polymerization and starch gelatinization (Cunin et al., 1995; Lund, 1984; Resmini & Pagani, 1983). Both structural changes are competing for water and antagonistic because protein polymerization, leading to a continuous and strengthened network, is opposed to starch swelling and gelatinization in the network interspaces (Resmini & Pagani, 1983). Pasta should release minimal material into the cooking water and must be firm and not unduly sticky when cooked for maximum consumer acceptance (Grant, Dick, & Shelton, 1993; Lucisano et al., 2012; Rakhesh et al., 2015). Cooking water properties could be affected by the type and concentration of solids that represent an important issue in food service appliance. Already Malcolmson and Matsuo (1993) highlighted the importance of cooking medium composition for the textural quality of spaghetti, but on laboratory scale.

Conventional and unconventional processing of food

Food processing can be defined as a set of unit operations by which raw foodstuffs are made suitable for consumption, cooking or storage. Among the large variety of processing (fermentation, heating, drying, mechanical processes etc.), heating is extensively used in food technology. It is well known that thermal treatments (conventional processing) cause denaturation and gelatinization of protein and starch, respectively, leading to an increase of their digestibility (Linnemann et al., 2006). During the centuries, the use of heat changed from domestic use to more industrialized process with modern thermal processing. In the food service sector, thermal processing has been translated into ovens, grills, fryers, pasta cookers, hobs and braising pans. Accessories and automatic temperature controls allow to adjust the temperature according to specifications and this represents a great tool. Specifications are set by kitchen operators during the use in the kitchen and with engineers in the R&D phase in the manufacturing, respectively.

Unconventional technologies are a group of technologies based on driven forces different from heating. For instance, mechanical and chemical stresses occur during the application of ultrasounds and high pressure. The main purpose of unconventional technologies is to obtain foods with improved nutritional and sensory properties, modify functional properties and/or reduce costs in comparison with conventional technologies (Raso & Barbosa-Cánovas, 2003). However, any process used to do so on laboratory scale might result differently when applied on industrial scale. For this reason, nowadays, the challenge for food scientists is first to understand the impact of unconventional technologies in order to obtain foods with desired characteristics and second to collaborate with engineers for their industrialization.

Among the unconventional technologies, the most promising ones appear to be ultrasound (US) and high pressure homogenization (HPH). US techniques use acoustic waves at frequencies higher than those perceived by human hearing (>18 kHz) (Patist & Bates, 2008). During US treatment, mechanical wave propagation into a fluid causes cavitation, which is the spontaneous formation and violent collapse of small bubbles that leads to the generation of local extreme temperatures (1000-5000 K) and pressures (10-5000 MPa). Physical (microject, turbulence, shear forces) and chemical phenomena (formation of free radicals) occur (Gogate, Wilhelm, & Pandit, 2003; Leighton, 1995). HPH technology consists of pressurizing a fluid to flow through a narrow gap valve (Dumay et al., 2013). During HPH treatment, the fluid undergoes intense mechanical forces and elongational stresses at the valve entrance and in the valve gap, while turbulence, cavitation and impacts with the solid surface occur at the gap outlet (Floury et al., 2004; Floury, Legrand, & Desrumaux, 2004). Efforts have been made to translate laboratory scale devices into industrial ones, but still applications are limited. Power ultrasounds have been commercially used in different food science applications such as emulsification, dispersion of solids, crystallization, de-gassing, and extraction (Martini, Potter, & Walsh, 2010). HPH has been applied mostly for the stabilization of food and dairy emulsions, and different types of equipment now exist, both prototype or industrial scale equipment, for example: Microfluid^{PM} technology, Nanojet^{PM}, jet homogenizers, and Emulsiflex from Avestin (Paquin, 1999).

RESEARCH NEEDS

So far, in most cases, the research and development in the manufacturing of professional appliances has been entrusted to engineers having a technical background. The performance of the food process is validated on a culinary base by kitchen operators, instead. This dialogue has different languages and lacks a scientific knowledge of food and food processing. The new industrial needs call for professional figures who enable the communication between different functional areas and departments, merging skills and knowledge about food with an integrated approach. Following this need, the food scientist becomes an interpreter and facilitator in the dialogue between engineers and kitchen operators. The food scientist recognizes the need for an integration of the two different approaches and defines food science-based methods for investigating and optimizing the food processes in the food service sector. The continuous cooking of pasta in pasta cookers is a representative case study to analyze such phenomenon.

Despite the huge number of studies available in the literature on pasta cooking, and the effect of conventional and unconventional technologies on food, there is no information on the continuous cooking procedure of pasta in pasta cookers and even more so on optimization strategies. In addition, almost all studies in the literature are based and focused on domestic or industrial procedures (Fusi, Guidetti, & Azapagic, 2016). In particular, the role of the cooking water characteristics resulting from continuously cooked spaghetti on the leaching behaviour, cooked pasta, and thus cooking procedure related issues has not been elucidated yet. The simulation of the continuous cooking procedure on laboratory scale is needed to identify quantitatively the empirical evidences favoring the understanding of the mechanisms inherent to the process of cooking. This knowledge is fundamental for giving a boost to

optimization strategies, which are represented by both conventional and unconventional technologies, whose role has never been explored.
All this information obtained on laboratory scale is also essential in view of the definition of process conditions in the professional appliance on industrial scale. In fact, it should be underlined that most of the studies are based on laboratory scale devices and it is well known that the effectiveness of the process is heavily scale dependent and that the results cannot be readily transferred to industrial level. This reinforces the need of studies based on an industrial scale perspective and with a food science-based approach in the attempt to establish a food-science based dialogue between engineers and kitchen operators while optimizing food processes.

AIM AND OUTLINE OF THIS PH.D. THESIS

This Ph.D. thesis aimed to propose a new approach for food scientists in the food service sector to fulfil the gap between engineers and kitchen operator perspectives. To this aim, the study case of the continuous cooking procedure in professional pasta cookers was chosen. In fact, the pasta cooker represents an emblematic case of food service requests to the manufacturer. Kitchen operators ask to the appliance for stress inputs minimization, safety, high efficiency and productivity. Consumers more and more rise the expectations in terms of the quality of food, which has to be promptly served always fresh-like.
In particular, the research was divided into two parts (Figure 1.3).

In the first part, the effect of continuous cooking on cooking water properties and cooked pasta quality was investigated for up to 13 batches. In Chapter 2 the continuous cooking procedure was simulated on a laboratory scale. The effect of the procedure on technological properties (solid content, cooking loss, swelling index) and textural parameters (firmness and stickiness) of pasta, and physical properties (solid content, rheological properties) of cooking water was studied. Chapter 3 aimed at understanding the effect of the procedure on the leaching behaviour of pasta and the cooking water (w/o pasta fragments) composition and foaming. In Chapter 4, US and HPH treatments were applied to retain fresh-like physical properties (turbidity and rheological properties) of cooking water obtained from continuously cooked spaghetti on laboratory scale.

In the second part, unconventional (US) and conventional (cooking temperature) technologies were applied on cooking water in the attempt to optimize the continuous cooking procedure in pasta cookers. Chapter 5 was addressed to the formulation of the technology concept of a multipurpose US bath system in the pasta cooker (TRL 2). The theoretical feasibility of US bath system as foam breaker, cooking water viscosity reducer and well surface cleaner was discussed. Finally, in Chapter 6, the effect of managing the power rating at 0/off, 1, 3, 6 kW power on appliance performance (energy efficiency and water balance), cooking water properties (solid content and pH) and technological properties of pasta (optimal cooking time, weight increase, water absorption and cooking loss) for a single batch and during continuous cooking (with 1 and 6 kW power) of 7 batch was investigated (TRL 3).

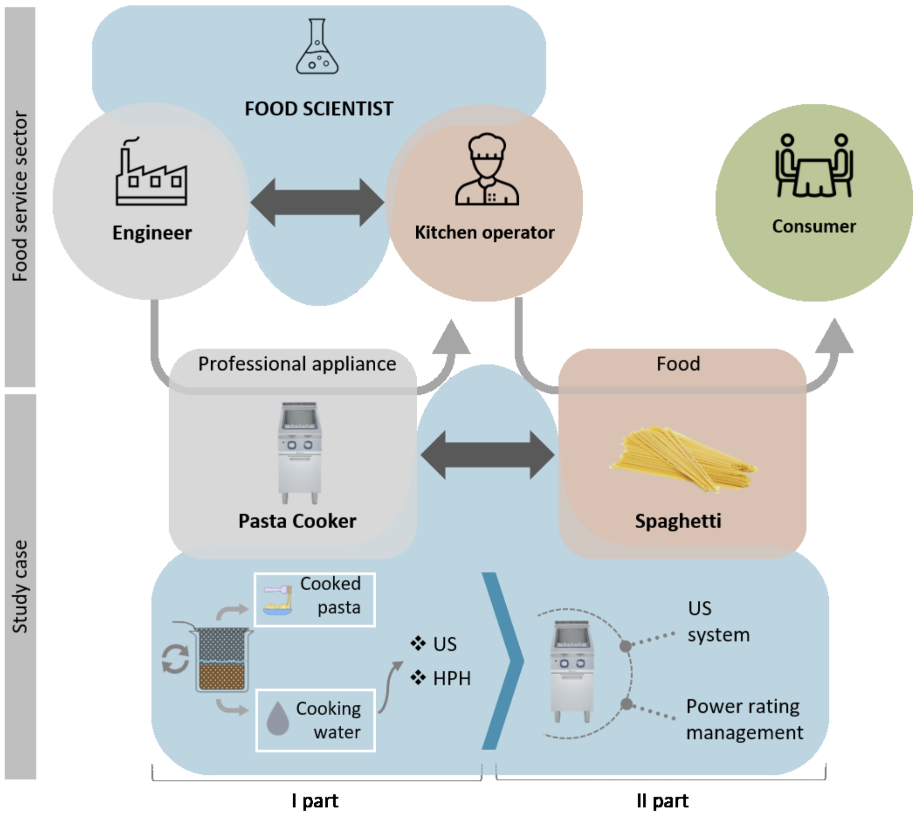


Figure 1.3. Scheme of the overall research of this Ph.D. thesis.

Part I

Continuous cooking procedure of pasta in pasta cookers

Chapter

2

Effect of continuous cooking on pasta quality and cooking water properties

INTRODUCTION

It is generally accepted that texture is the main criterion for assessing overall quality of cooked pasta (Edwards et al., 1993). Proper evaluation of pasta cooking quality requires consideration of a number of factors including firmness, surface stickiness, cooking tolerance, water absorption, and loss of solids to cooking water (Manser, 1981). Pasta firmness is promoted by a protein continuous network entrapping starch components. On the contrary, pasta tenderness results from a prevalence of starch swelling along with exudate loss, promoting the formation of protein coagulates in discrete masses lacking a continuous network (Bonomi et al., 2012; Cuq, Abecassis, & Guilbert, 2003; de Noni & Pagani, 2010; Dexter, Dronzek, & Matsuo, 1978). Semolina protein content and gluten strength are important prerequisites for superior pasta cooking quality (D'Egidio et al., 1990; Dexter et al., 1978; Peyron et al., 2002). Protein content is classified as typical when between 11 and 16% (Del Nobile et al., 2005; Sissons, Soh, & Turner, 2007), while gluten strength is primary a function of the density of reversible disulphide bonds, which are responsible of the desired solid-like behaviour in cooked pasta (Edwards et al., 2001; Rao et al., 2001; Sissons, 2008). Stickiness is one of the most desired quality parameters and it is related to the amount of amylose leached from the gelatinized starch granules. The higher the cooking loss, i.e. leaching of material from the outer layer of pasta in cooking water, the stickier the pasta is (Del Nobile et al., 2005; Dexter et al., 1983; Dziki & Janusz, 2005; Soh, Sissons, & Turner, 2006). These solids are mainly amylose with a small amylopectin presence only, and a small amount of proteins and nonstarch polysaccharides (Matsuo & Dexter, 1980). Pasta stickiness results from substances escaping from the protein network and adhering to the surface of cooked pasta and is related to the proportion of surface material that can be rinsed from the cooked pasta following drainage (D'Egidio et al., 1982). Even though the role of the cooking medium characteristics has not been fully elucidated yet, semolina characteristics (e.g. protein content and quality, starch damage related to granulation), processing (e.g. low and high temperature drying), cooking conditions (e.g. water characteristics, cooking time) and consuming modality (e.g. length of time between draining and testing) are well known factors influencing stickiness (Cunin et al., 1995; D'Egidio et al., 1990; Del Nobile et al., 2005; Dexter et al., 1983; Grant et al., 1993; Matsuo & Dexter, 1980).

Similarly, although the mechanism of solid leaching in cooking water during cooking on a laboratory scale has been extensively studied, to the authors' best knowledge, no reports about cooking in pasta cookers are present in the scientific literature. Moreover, data on cooking water characteristics as obtained from continuously cooked pasta are absent (Korzeniowska et al., 2005).

AIM OF THE STUDY

The aim of the present study was to investigate the continuous cooking procedure in pasta cooker and simulate the latter under controlled conditions. Continuous cooking was run for 7 batches and its effect on overflow and wastewater volume in a pasta cooker was studied. The procedure was then simulated for the first time on laboratory scale and the effect of 12 batches on the technological and textural properties of pasta, and the technological and rheological characteristics of cooking water was examined. To this aim, spaghetti was chosen since it is the most popular pasta form that manufacturers produce today.

MATERIALS AND METHODS

Materials

Durum wheat spaghetti (2 mm diameter) was purchased from a specialized supplier to the food service sector (Marr, Italy). The composition of the pasta supplied by the manufacturer (Rummo, Benevento, Italy) was: protein 125 g kg^{-1}, carbohydrate 715 g kg^{-1}, fiber 28 g kg^{-1}, and fat 16 g kg^{-1}.

Cooking procedure

The following professional cooking procedure was performed in a pasta cooker (Electric Pasta Cooker, 1 Well 40 L, Electrolux Professional S.p.A., Pordenone, Italy). Spaghetti strands (3 kg) were placed in the steel vessel. The spaghetti was cooked for 11 min in 36 L of boiling tap water with no salt added. The pasta was strained above the tank and fresh water was added to make up the initial volume. 7 batches were cooked.

The laboratory-scale cooking procedure was set up to simulate the continuous cooking procedure used by food service operators. The pasta cooking batches are added one after the other and thus the service to the customer is as much continuous as possible. The flow chart of a single cooking cycle is shown in Figure 2.1. To perform continuous cooking a colander fitting in a 500-mL beaker was used. Spaghetti strands (25 g) were cut into equal lengths of 50 mm and placed in the colander (Figure 2.1a). The spaghetti was cooked in 300 mL of boiling tap water with no salt added (Figure 2.1b). Stirring was frequently performed, especially in the first cooking minutes, with a smooth plastic stick. Pasta was then strained and rinsed with boiling tap water over the beaker (Figure 2.1c) to reach 300 mL of volume for the next batch and retain solids in the cooking water. Up to 12 batches were cooked in the same colander with the same procedure as before.

The cooked spaghetti from each batch was analyzed for cooking loss, swelling index, and textural characteristics. Cooking water from each batch was analyzed for solid content and rheological properties.

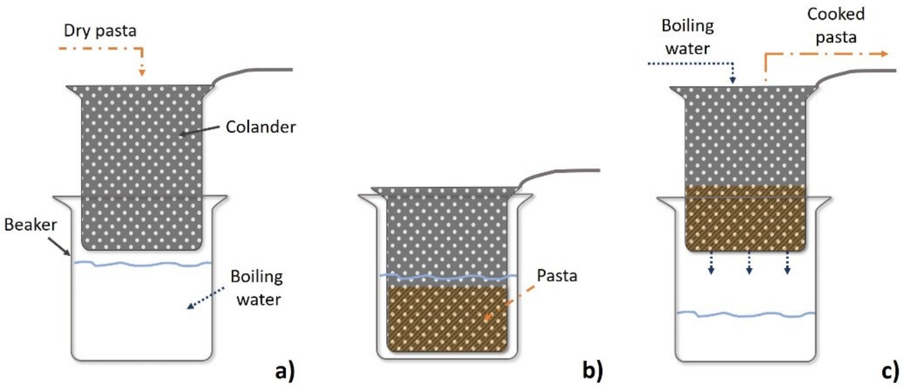


Figure 2.1. Flow chart of cooking cycle: **a)** Pasta loading, **b)** Cooking batch, **c)** Rinsing, straining, unloading.

Determinations

Optimal cooking time

During cooking, the optimal cooking time (OCT) was evaluated by taking a sample strand of spaghetti every 30 s and observing the time of disappearance of the core of the strand, by squeezing it between two Plexiglas® plates, according to the AACC Approved Method 66-50 (AACC, 2000). The time at which the core completely disappeared was taken as the OCT.

Cooking loss and water solid content

According to the Approved Method 66-50 (AACC, 2000), slightly modified, pasta was poured into a Bückner funnel over an aluminum vessel while collecting cooking water and rinsed with 100 mL of cold distilled water. Rinsing and cooking waters were combined and hereafter referred to as “cooking water” for simplicity. For the professional cooking procedure only, a volume of cooking water (300 mL) was collected from the pasta cooker tank after the straining step. The cooking water was weighed, placed in an air oven at 105 °C and evaporated until a constant weight was reached. The cooking loss of pasta was expressed as the percentage of the solid substance lost into the cooking water referred to the total dry pasta cooked at each cooking batch and the solid content of cooking water as the percentage of solid substance in the cooking water before drying.

Overflow and wastewater volume in the pasta cooker

The overflow was measured as the time per cooking batch in which foam formation made the water to go into the overflow drain. The wastewater from the overflow drain was the volume (L) of water measured by weighing the discharged water from the drainage pipe of the appliance.

Swelling index

The swelling index of cooked pasta (g water g^{-1} dry pasta) was determined according to the procedure described by Foschia et al. (2015) Pasta was weighed after cooking and dried in an air oven at 105 °C to a constant weight. The swelling index was expressed as:

$$\text{Swelling index} = \frac{W_c - W_d}{W_d} \qquad \text{(Eq. 2.1)}$$

where W_c is the weight of cooked pasta (g) and W_d is the weight of the pasta after drying (g).

Textural characteristics

The textural properties of cooked pasta samples were evaluated using a Texture Analyser (TA.XT plus, Stable Micro Systems Ltd., Godalming, UK) equipped with a 5 kg load cell. Before being tested, the pasta samples were allowed to rest at 25 °C for 10 min in a covered container (Dexter et al., 1983). Only for firmness, the cooked pasta was rinsed with 100 mL of cold distilled water.

Pasta firmness was determined according to the Approved Method 66-50 (AACC, 2000) using a light knife blade (A/LKB) (speed 0.17 mm s^{-1}) and was expressed as the maximum cutting force (N) required to cut five pasta strands. Pasta stickiness was evaluated using a pasta stickiness rig (HDP/PFS) at a compression speed of 0.5 mm s^{-1} and a compression force of 1 kg for 2 s. It was defined as the maximum peak force (N) to separate the probe from the surface of the five pasta strands upon probe retraction.

Rheological properties

The rheological measurements were carried out using a RS6000 Rheometer (Thermo Scientific RheoStress, Haake, Germany), equipped with a coaxial cylinder geometry (CCB25 Din) and a Peltier system for temperature control. Cooking water was allowed to cool down in a water bath (15±5 °C) for 30 min under gentle magnetic stirring. Measurement were conducted at 25 and 80 ± 0.01 °C. After loading, the samples were allowed to rest and equilibrate for 5 min at the selected temperature. Steady shear measurements (flow curves) were performed over a shear rate range from 3 to 100 s^{-1}. The power law model was used to fit the flow data:

$$\sigma = K\dot{\gamma}^n \qquad \text{(Eq. 2.2)}$$

where σ (Pa) is the shear stress, $\dot{\gamma}$ (s^{-1}) is the shear rate, K (Pa·s^n) and n (dimensionless) are the consistency and flow coefficients, respectively.

The consistency coefficient (K) was used to determine the viscosity-concentration relationship. The concentration dependence of the consistency coefficient at the two temperatures was examined using an exponential model and a power law model (Marcotte, Taherian Hoshahili, & Ramaswamy, 2001), respectively as follows:

$$K = ae^{(bC)} \quad \text{(Eq. 2.3)}$$

$$K = aC^{b} \quad \text{(Eq. 2.4)}$$

where K ($Pa \cdot s^n$) is the consistency coefficient and C ($g\ kg^{-1}$) is the solid concentration of cooking water. Parameters a and b were calculated for each model.

Statistical analysis

All experiments were performed in triplicate unless otherwise mentioned. Textural data for firmness and stickiness are mean of thirty and fifteen measurements (from three different cooking replications), respectively. Statistical differences in pasta and solid content in cooking water were determined by one-way analysis of variance (ANOVA) and Tukey's comparison test ($p<0.05$). The goodness-of-fit was evaluated based on statistical parameters of fitting (coefficient of determination, R^2 and standard error). The statistical software, R (The R foundation for statistics, v. 3.0.3), was used for the analysis.

RESULTS AND DISCUSSION

Continuous cooking procedure was first investigated in a professional pasta cooker for 7 batches in close collaboration with kitchen operators of the R&D department of Electrolux Professional S.p.A. Above this batch threshold pasta is perceived as sticky and the cooking water is turbid with off-flavour such as the kitchen operators ask to empty the well and use fresh water. Moreover, an excessive formation of foam and waste of water were observed. Solid content in the collected cooking water progressively increased approaching a saturation point (Figure 2.2). The overflow occurred for approximately 10 minutes per cooking batch with a wastewater volume of 21 L, counting 58.3% of the initial well volume. Water consumption during cooking is due to evaporation, water absorption by the product and water loss through the overflow drain that occurs as a consequence of foam formation due to leached components from pasta (Szczesniak & Farkas, 1962; Thewissen et al., 2011). These results were useful to delve more deeply into the procedure used in food service kitchens and the related issues. Therefore, to reduce wastewater and address product/water changes, the wastewater into the overflow drain might be the water consumption cause to be faced.

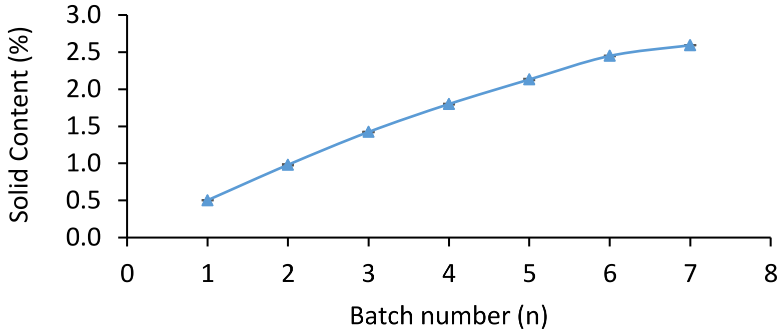


Figure 2.2. Solid content of cooking water in the pasta cooker as a function of pasta batch number.

For this purpose, the professional pasta cooking procedure was simulated on the laboratory scale (Figure 2.1) to investigate the effect of continuous cooking on pasta quality and cooking water properties under controlled conditions.

The OCT, i.e. the time when the central starch core was no longer visible and the starch can be considered to be fully gelatinized (Sissons et al., 2007), was 13 min 45 s.

Table 2.1 shows the solid content in the cooking water, as well as pasta cooking loss and swelling index of 12 pasta batches, corresponding to more than 3 hours of continuous cooking. As expected, the solid content progressively increased, similar to solid content of cooking water in the pasta cooker (Figure 2.2). This solid concentration gradually approached a saturation point, which was not achieved within the batch range of this experimental work.

Increasing the batch number, cooking loss and swelling index of the spaghetti progressively decreased from 5.27 to 3.57% and from 1.95 to 1.60% (g water g^{-1} dry pasta), respectively (Table 2.1). Cooking loss is commonly used as a predictor of overall cooking performance by both consumers and kitchen operators, and it is generally accompanied by a mass transfer of water from the cooking medium to the pasta, here quantified by the swelling index (Gull, Prasad, & Kumar, 2015; Rakhesh et al., 2015; Tudorică et al., 2002). Pasta that features up to 6, 8 and 10% solid loss is considered quite good, regular and poor, respectively (Hummel, 1966). Consequently, pasta under our investigation can be considered good, which was confirmed by swelling index values in agreement with the literature (Rakhesh et al., 2015; Sissons et al., 2012). During continuous cooking, the increase of solid content in cooking water would limit an efficient heat and mass transfer through the strand (reduced concentration gradient) leading to lower hydration and partly swelling of starch granules at OCT. The lack of the arrangement of starch polymers inside the granule would result in lower solid leaching from the pasta matrix during cooking (Marti, Seetharaman, & Pagani, 2013). This finding supports the hypothesis of Sissons and Batey (2003) that lower swelling is related to a reduced tendency for the granules to leach their contents into the surrounding liquid. Moreover, solids in cooking water might act as a physical barrier on product surface hindering particles from leaching, which probably fill small pores in the gluten network. Furthermore, part of the solids leached out of the granule may be aggregated in the protein network partially restricting further granule swelling. Amylose is believed to act as a restraint on swelling and starch granules do not show complete swelling until amylose has been leached out of the granules (Hermansson & Svegmark, 1996). These results can hardly be compared with data of the literature since the role of cooking water on cooking loss and swelling index has been investigated in terms of cooking water composition instead of leached solid concentration, as in the present investigation. Specifically, Malcolmson and Matsuo (1993) reported greater cooking loss with increased water hardness and when the pH was raised over 8. The same was concluded when pasta was cooked in water with salt (Majzoobi, Ostovan, & Farahnaky, 2011).

Table 2.1. Effect of batch number on technological properties of cooking water and pasta samples.

Batch (n)	Solid content (%)	Cooking loss (%)	Swelling index (g water g^{-1} dry pasta)
1	0.53[e]	5.27[a]	1.95[a]
2	0.77[e]	5.03[ab]	1.92[a]
3	1.37[d]	5.02[bc]	1.90[a]
4	1.62[d]	4.82[bc]	1.87[ab]
5	2.12[c]	4.54[bcd]	1.88[a]
6	2.41[bc]	4.33[cd]	1.84[ab]
7	2.65[b]	4.11[de]	1.86[ab]
9	3.28[a]	4.10[de]	1.75[b]
12	3.66[a]	3.57[e]	1.60[c]

[a]Values followed by the same letter in the same column are not significantly different ($p<0.05$)

Figure 2.3 shows textural values of spaghetti cooked under continuous cooking. The firmness value of the first batch (i.e. pasta cooked in fresh tap water) can be ascribed to the protein content, indicated in the label by the manufacturer. Increasing the number of cooking batch would make the pasta significantly firmer ($p>0.05$). This can be due to the solid retention inside the

starch-protein structure and the partial swelling of starch granules, also reflected in the decrease in cooking loss. This further supports our hypothesis that soluble material was entrapped and did not diffuse in the cooking water. Upon cooling, aggregated amylose outside the granules retrograded, stabilizing the gluten network and adding firmness to the pasta (Hermansson & Svegmark, 1996). Also other starch modifications (e.g. amylopectin melting) may supersede amylose content in imparting firmness (Cocci et al., 2008).
Stickiness did not differ significantly ($p<0.05$) remaining surprisingly unaffected within the range of batch number tested (Figure 2.3). This can be explained by both mass and composition factors thus referring to surface material quantity and quality, respectively. Surface material quantity might change because of surface material leaching kinetic. Constant stickiness values with the higher batch number indicated constant material amount stuck to the surface. This result disproved the hypothesis that lower cooking loss (Table 2.1) is attributed to lower stickiness (Majzoobi et al., 2011; Sissons et al., 2008), while bearing out that total solids lost to cooking water might not necessarily be related to stickiness, as indicated by Dexter et al. (1983) Surface material quality might change because of the extent of starch gelatinization (Sozer, Dalgiç, & Kaya, 2007) and the amount of soluble carbohydrate, amylose and amylopectin fragments, exuding from the starch granules during cooking (de Noni & Pagani, 2010; Grant et al., 1993). Since instrumental stickiness did not change during continuous cooking, the mouthfeel stickiness might be related to flow properties of cooking water (Szczesniak & Farkas, 1962).

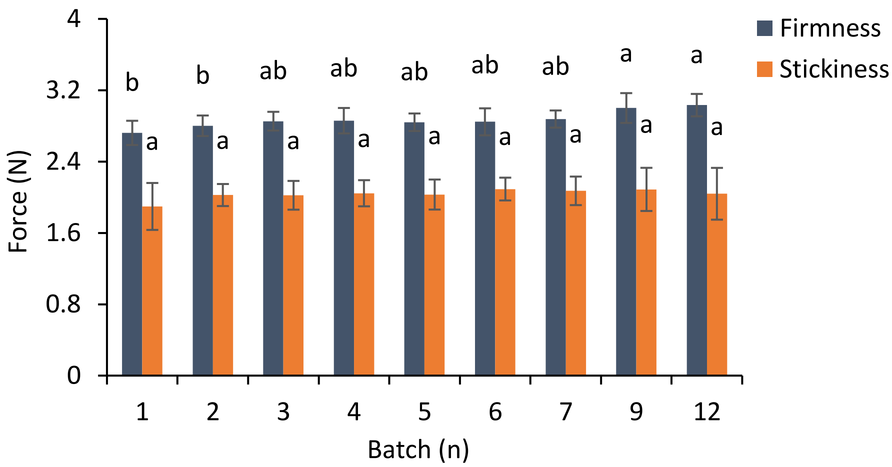


Figure 2.3. Firmness and stickiness values (N) of the cooked pasta as a function of batch number; means ± standard deviations with the same letter are not significantly different ($p<0.05$).

In light of the pasta quality values observed, the main issue of the continuous cooking procedure may be related to cooking water properties, which is indeed indicated by food service operators. Flow properties were investigated at room temperature (25 °C) and at the closest temperature to boiling point (80 °C), simulating the condition of use. Figure 2.4 shows the flow curves at 25 °C of cooking water of different batches. In accordance with Che et al. (2008) for starch solutions, flow curves of the dispersions showed shear thinning behaviour under steady shear flow and the same trend was observed for flow curves at 80 °C (data not shown). The decrease in viscosity with the increase in shear rate can be attributed to the disentanglement of polymer chains under shear flow and breaking of possible structure in solution. This flow behaviour was described by a power law model (Eq. 2.2) and the corresponding parameters are summarized in Table 2.2. The flow index (n) is dimensionless and reflects the closeness to Newtonian flow (n=1), while the consistency coefficient (K) indicates viscosity at a shear rate of 1.0 s^{-1} (Rao, 2007). The coefficients of determination (R^2) were very close to 1, indicating that the selected model was adequately suitable for describing the flow behaviour of samples (Holdsworth, 1971). Flow index values of 0.83-0.98 at 25 °C are consistent with a shear thinning behaviour, while at a low batch number and 80 °C Newtonian behaviour was observed (Marcotte et al., 2001). These results may be attributable to the relatively low concentration of solids. At 25 and 80 °C, n decreased with the increase in batch number due to more entanglements that break upon flow. Increasing the temperature from 25 to 80 °C led to higher flow index, which indicated that cooking water tends to be more shear thinning at lower temperatures. K values increased from 1.4 to 31 $mPa\cdot s^n$ at 25 °C and from 0.5 to 21 $mPa\cdot s^n$ at 80 °C increasing batch numbers. The viscosity increase due to a higher solid content may result from increased restriction of molecular motion due to entanglements between polymer chains (Karazhiyan et al., 2009; Lapasin & Pricl, 1995). As expected, K decreased with the increase in temperature, indicating a lower apparent viscosity at higher temperatures (Holdsworth, 1971; Maskan, 2000).

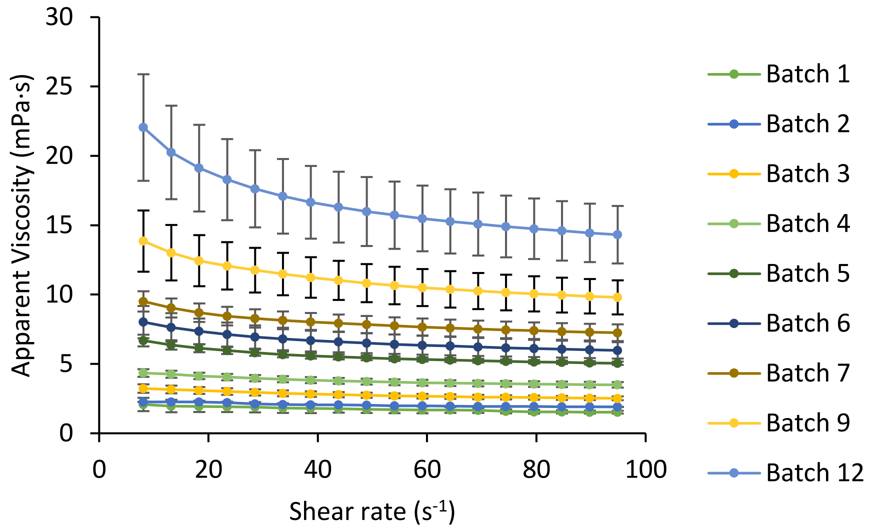


Figure 2.4. Apparent viscosity as a function of shear rate for different batch numbers of the cooking water at 25 °C.

The effect of solid concentration on flow behaviour of cooking water can be obtained from parameters of rheological models, which are generally power or exponential relationships using apparent viscosity values at 50 s^{-1}, which corresponds to effective oral shear rate (Karazhiyan et al., 2009; Nurul, Mohd. Azemi, & Manan, 1999). The consistency coefficient (K) instead of the apparent viscosity at 50 s^{-1} was used since pasta cooking water is not intended for consumption. The coefficients of determination (R^2) were higher for the exponential model (Eq. 2.3) than the power law (Eq. 2.3) model. Therefore, the former was selected as being more suitable in describing the solid concentration effect (Ibarz, Vicente, & Graell, 1987) and the regression model parameters "a" and "b" are summarized in Table 2.3. At 80 °C and thus close to the temperature of use in pasta cooker, parameter "a" was lower while parameter "b" was higher, indicating a stronger dependency of the consistency coefficient on concentration. These results are in line with those reported by Marcotte et al. (2001), who investigated exponential models for food hydrocolloids such as carrageenan, pectin, gelatine, starch, and xanthan. The professional continuous cooking procedure was successfully simulated on a laboratory scale and this was confirmed by similar values of solid content in cooking water. Taking into consideration the indication provided by food service operators during the preliminary tests on the pasta cooker, batch 7 is an acceptability threshold for working conditions and should be always included when investigating pasta continuous cooking.

Table 2.2. Power law parameters for cooking water at different batch number and temperatures of 25 and 80 °C.

Temperature (°C)	Batch (n)	n	K (mPa·s^n)	R^2
25	1	0.986±0.016	1.4±0.4	0.997
	2	0.914±0.012	2.8±0.3·10^{-2}	0.998
	3	0.899±0.008	4.0±0.3·10^{-2}	0.999
	4	0.896±0.002	5.3±0.3·10^{-2}	0.999
	5	0.885±0.005	8.3±0.9·10^{-2}	0.999
	6	0.888±0.004	9.6±3.1·10^{-2}	0.999
	7	0.894±0.001	11.9±0.7·10^{-2}	1.000
	9	0.864±0.005	18.9±0.2	0.999
	12	0.834±0.005	30.7±2.2	1.000
80	1	0.969±0.039	0.5±0.1	0.982
	2	1.021±0.037	0.8±0.1	0.994
	3	1.004±0.043	1.2±0.2	0.998
	4	0.944±0.026	2.0±0.2	0.999
	5	0.920±0.059	3.2±1.0	1.000
	6	0.924±0.029	3.3±0.4	0.999
	7	0.917±0.038	4.4±0.9	1.000
	9	0.811±0.133	12.5±1.0	1.000
	12	0.777±0.133	21.9±2.4	1.000

Power law parameters: K, consistency coefficient; n, flow behaviour index; means ± standard deviation

Table 2.3. Concentration dependence coefficients (± standard errors) for consistency coefficient of cooking water (Eq. 2.3).

Temperature (°C)	*a*	*b*	R^2
25	1.21·10^{-3}±0.09	0.87±0.04	0.98
80	0.27·10^{-3}±0.15	1.14±0.06	0.98

CONCLUSIONS

The effect of professional continuous cooking on cooked pasta quality and water properties was investigated for the first time by simulating professional pasta cooking on a laboratory scale. Up to more than 3 hours of continuous cooking (i.e. 12 cooking batches) resulted in a decrease in cooking loss and a lower swelling index of spaghetti. The solid content in cooking water progressively increased from to 0.53 to 3.66%, leading to a shear thinning behaviour of cooking water, which exhibited Newtonian behaviour at low solid content but high temperature. Increasing the cooking batch number during continuous cooking made the pasta firmer (up to 3.03 N), due to the solid retention inside the starch-protein network and possibly the only partial swelling of starch granules. Surprisingly, stickiness remained unaffected (2.04 N) during the continuous cooking procedure. In light of these results, kitchen operators were reassured about pasta stickiness while the basis for a food science based method was established.

Chapter

3

Effect of continuous cooking on leaching behaviour of pasta and related cooking water properties

INTRODUCTION

The cooking of pasta in an excess of fresh water at boiling temperature starts with a water flow that penetrates from the surface of pasta to the core (Cocci et al., 2008; Martinez et al., 2007). The water uptake rate is controlled by two occurring phenomena: the water diffusion and the macromolecular relaxation. The water diffusion through the strand (stochastic phenomenon) is driven by a concentration gradient and controls the hydration process at the earlier stage. As the water concentration increases, at an elevated temperature, starch crystalline domains melt very fast. Water acts also as a plasticizer and increases polymer mobility. This allows the macromolecular relaxation phenomenon to occur, since in the dry state starch domains act as physical constraints to prevent the relaxation toward the equilibrium conformation (Del Nobile et al., 2005; Del Nobile et al., 2002). As dry pasta has a limited moisture content, the water penetration flow governs starch gelatinization and (further) protein polymerization. During cooking, starch granules adsorb water and strongly swell. Then the melting of amylopectin crystals begins which disrupts the granular structure (Cunin et al., 1995). Simultaneously, gluten proteins can polymerize through disulfide (SS) bonds at temperatures above 55 °C and moisture contents of 20% (Weegels & Hamer, 1998). These SS bonds can be formed by oxidation of free thiol (SH) groups (Wieser, 2003) or SH-SS exchange reaction (Kuninori & Sullivan, 1968). The impact of the resulting continuous and strengthened protein network is opposed to starch swelling and gelatinization in the network interspaces (Pagani, Resmini, & Dalbon, 1989; Petitot, Abecassis, & Micard, 2009). From this competition results the leaching and final pasta quality (Lucisano et al., 2012; Rakhesh et al., 2015).

Material leaching into cooking water is due to starch gelatinization and the increased mobility inside the strand during hydration. Regarding starch components, mainly amylose leaches into the cooking water and small amylopectin molecules displace on the pasta surface (de Noni & Pagani, 2010; Singh et al., 2003). Regarding proteins, a very loose gluten matrix allows for a large amount of exudate to escape during starch granule gelatinization (Matsuo et al., 1992; Resmini & Pagani, 1983; Yaseen, 1993). Among the various factors influencing the hydration process and thus leaching behaviour during pasta cooking (described in Chapter 2), the role of the cooking water characteristics has not been fully elucidated yet. Some authors reported higher total organic materials in the rinse and cooking waters and higher cooking losses with increased water hardness (Dexter, Matsuo, & Morgan, 1983). Other workers have demonstrated the importance of cooking water pH on the cooking quality of pasta. Adjusting the pH of mineral water (Alary et al., 1980) and distilled water (Abecassis, Alary, & Kobrehel, 1981) to 6, surface disintegration decreased and cooking losses lowered. Spaghetti cooking quality peaked at pH 6 and declined on either side (Feillet, 1984).

Despite the enormous size and economic value of the food service sector, almost all studies are based and focused on the domestic preparation procedure (Fusi et al., 2016). The latter implies cooking by using a pot filled with tap water on an electric or gas source for a single cooking batch (Oliveira, Mitchell, & Badni, 2012). Instead, in the food service the pasta cooker is used, and the continuous cooking procedure is performed. Therefore, along with the procedure, the impact of the increasing solids in cooking water on the leaching behaviour of pasta, the composition of pasta and cooking water, and the foaming properties of the latter has never been explored.

AIM OF THE STUDY

The aim of the present investigation was to study the impact of continuous cooking on the technological properties and leaching behaviour of pasta and the cooking water composition. Moreover, the polymerization behavior of proteins and the foaming properties of cooking water upon the continuous cooking procedure were investigated. Finally, the role of cooking water pH and mineral content for a single cooking batch, to get rid of the solid content factor, was taken into account.

MATERIALS AND METHODS

Materials

Durum wheat spaghetti (2 mm diameter) was purchased from the same specialized supplier to the food service sector (Marr, Italy) as in Chapter 2. All used chemicals, solvents, and reagents were at least of analytical grade and purchased from Sigma–Aldrich (Bornem, Belgium), unless specified otherwise.

Cooking procedure and sample collection

The laboratory scale continuous cooking procedure, as explained in Chapter 2 (page 28), was performed with some modifications for up to 13 batches. After collection and cooling, the cooking water was divided in two parts with comparable composition by placing a plastic wall in the middle of the container. One part was then centrifuged at 3000 g for 15 min at 20 °C and the further called "supernatant" was collected.

Cooking water and supernatant were analyzed for pH and foaming properties. For the analysis of composition and protein extractability, all samples were freeze-dried and ground in a universal mill (IKA Labortechnik, Staufen, Germany). Batches 1, 2, 6, 7, 12, 13 after cooking in tap water, as well as batch 1 after cooking in distilled water and adjusted pH were investigated.

DP, CP, W and S followed by the number of batch will refer to dry (uncooked) pasta, cooked pasta, cooking water and its supernatant, respectively.

Dry matter and cooking loss

Dry matter (DM, expressed in %) was determined in triplicate for dry and cooked spaghetti, cooking water and supernatant as the mass loss during freeze-drying. Cooking loss (CL), i.e. the % of dm material leached into the cooking water, was determined as the dm material leached into the cooking water of optimally cooked spaghetti until the selected cooking batch:

$$\mathrm{CL}\ (\%) = \frac{\Sigma \mathrm{CL}'\ (\mathrm{g,\ dm})}{\Sigma \mathrm{DP}\ (\mathrm{g,\ dm})}\ \mathrm{x}\ 100 \qquad \text{(Eq. 3.1)}$$

where ΣCL' is the sum of dm weight (g) of material leached into the cooking water until the selected cooking batch, and ΣDP is the sum of dm weight (g) of dry (uncooked) pasta until the selected batch.

Water absorption

Water absorption (WA) was determined in triplicate and calculated by relating the weight increase between dry and cooked spaghetti to the dm content of dry pasta of the selected batch with correction for the cooking losses:

$$\mathrm{WA}\ \left(\frac{\mathrm{g}}{\mathrm{g\ dm}}\right) = \frac{\mathrm{CP\ (g)} - [\mathrm{DP\ (g)} - \mathrm{CL}'\ (\mathrm{g,\ dm})]}{[\mathrm{DP}\ (\mathrm{g,\ dm}) - \mathrm{CL}'\ (\mathrm{g,\ dm})]} \qquad \text{(Eq. 3.2)}$$

with CP cooked pasta, DP dry (uncooked) pasta (weight as is or on dm basis), and CL' cooking losses, i.e. the dm weight (g) of material leached into the cooking water at the selected batch.

pH

The pH was determined under gentle magnetic stirring (room temperature) with a pH meter HI 9025 (Hanna Instruments, Woonsocket, RI, USA). The pH of tap water was measured after boiling for 14 min and subsequent cooling to room temperature. It was then adjusted by adding HCl (0.5M).

Composition analysis

Starch contents were determined by gas-liquid chromatography of sorbitol acetate following starch hydrolysis, glucose reduction and derivatization as described by Courtin et al. (2000), and was calculated as 0.9 times the glucose content.

Protein contents were determined using the Dumas combustion method, an adaptation of the AOAC Official Method (AOAC, 1995) to a Dumas protein analysis system (EAS Vario Max C/N, Elt, Gouda, The Netherlands), using 5.7 as the conversion factor to calculate protein from nitrogen contents. Analyses were performed in triplicate and the results are expressed on a dry matter (dm) and wet basis (wb).

Ash contents were determined gravimetrically after combustion of the organic material in a muffle furnace at 590 °C, in accordance with the Approved Methods 08-01 (AACC, 1983).

Protein extractability

Size-exclusion high performance liquid chromatography (SE-HPLC) was conducted using a Shimadzu LC-2010 system (Kyoto, Japan) with automatic injection. The freeze-dried and grinded cooking water, supernatant, dry pasta and cooked pasta samples (corresponding to 1.0 mg dm proteins) were shaken (150 rpm, 60 min, room temperature) in 1.0 ml sodium phosphate buffer (50 mM, pH 6.8) containing 2.0% (w/v) sodium dodecyl sulphate (SDS, Acros Organics, Geel, Belgium), hereafter referred to as SDS containing medium. To evaluate extractability under reducing conditions, 1.0% w/v dithiothreitol (DTT, Acros Organics, Geel, Belgium) was added to the SDS containing buffer under nitrogen atmosphere, hereafter referred to as DTT containing medium. The protein extracts were filtered through a 0.45 µm membrane (regenerated cellulose; Alltech Associates, Deerfield, MA, USA) and loaded on a Biosep-SEC-S4000 column (Phenomenex, Torrance, CA, USA). The elution solvent was the SDS containing medium. The flow rate was 1.0 ml/min and the column temperature 30 °C. Protein elution was monitored at 214 nm. The injection volume was 20 µl. Measurements were conducted in triplicate.

The protein extractability in SDS containing medium (SDS-EP) was expressed as the ratio of proteins extractable under non-reducing versus under reducing conditions. For this, the area under the chromatogram of the extract in SDS containing buffer was calculated and is expressed as a percentage of the total area, i.e. the area in the chromatogram of the corresponding sample extracted with SDS and 1.0% DTT containing buffer.

Foaming properties

Foaming properties were determined with a standardized stirring test identical to the one of Wouters et al. (2016). An aliquot (50 mL) of cooking water or supernatant was placed in a graduated glass cylinder (internal diameter 60.0 mm) in a water bath at 25 °C. After equilibration to this temperature for 15 min, it was stirred for 70 s with a propeller (outer diameter 45.0 mm, thickness 0.4 mm) rotating at about 2000 rpm. After stirring, the propeller was immediately removed and the glass cylinder sealed with Parafilm M (Bemis, Neenah, WI, USA) to avoid foam disruption by air circulation. The foam capacity (FC) is the foam volume 120 s after the start of stirring. Foam stability (FS) is measured by determining foam volume after 60 min and expressing it as percentage of the FC. Based on the foam height and the cylinder internal diameter, foam volume (FV) was calculated and expressed in mL.

Statistical analysis

Samples were produced in threefold starting from scratch for all the cooking batches under investigation. Protein and starch contents, and protein extractability measurements were performed in triplicate for each of the sample. Statistical differences in cooked pasta, cooking water and supernatant were determined by one-way analysis of variance (ANOVA) and Tukey's comparison test ($p<0.05$). The goodness-of-fit was evaluated based on statistical parameters of fitting (coefficient of determination, R^2 and standard error). For each sample, means were compared and error bars or values in all figures and tables represent the standard deviation from the means. The statistical software R (The R Foundation for Statistics, v. 3.0.3) was used for the analysis.

RESULTS AND DISCUSSION

Effect of continuous cooking on pasta properties

During continuous cooking, visible pasta fragments are mechanically lost from the strand surface and edges that can be separated by centrifugation and represent the resulting pellet.

Dry matter of cooked pasta increased from batch 1 to batch 2 and then remained constant, indicating a lower loss of solids and/or a lower water soaking (Table 3.1). Dry (uncooked) pasta contained 11.3, 58.6 and 0.9% of proteins, starch and ash, respectively. Cooked pasta at different batches did not show significant differences ($p<0.05$) in starch contents, ranging from 20.7 to 23.6% (data not shown). Ash content was slightly higher for the later cooked pasta (0.21 to 0.30% for batch 1 to 13, respectively) and the same was for protein content, which increased from 4.1 to 4.4% (Table 3.1). Based on the spaghetti water sorption kinetic (Del Nobile et al., 2003), it can be inferred that the cooking water in which spaghetti is cooked with the continuous cooking procedure reduces the water concentration gradient between the cooking medium and the pasta matrix. Thus, in the experimental conditions here studied, the water diffusion phenomenon slowed down and the lack of plasticizer resulted in slower increase in the polymer macromolecular mobility. Less polymers were consequently leached into the cooking water. These results indicate that cooking pasta in the same water for hours did not impact the starch components loss but the one of proteins, which were retained more in the matrix for the later cooked pasta. This higher retention might result in different protein network properties, explaining the higher pasta firmness and different cooking water characteristics reported in Chapter 2. This hypothesis about the slower hydration kinetic was supported by the results on water absorption and cooking loss (Table 3.2). Water absorption of the pasta progressively decreased from 1.9 to 1.7 (g g^{-1} dm) and cooking loss from 7.41 to 3.77%, indeed. Results suggest that when spaghetti is cooked in fresh water, it is easy to control its optimal hydration level. However, when it was cooked in a more concentrated solution such as the batch 13 in the cooking water of the 12^{th} batch, water imbibition through the spaghetti strand reduced. This implies a lower hydration extent by the starch-gluten network and, consequently, the physical competition for the water molecules heightens between starch swelling and polymerized and polymerizing proteins (Resmini & Pagani, 1983). The lower hydration counteracts solid leaching at the optimal cooking time. In fact, cooking loss theoretically reflects the quantity of starch and other components that are released from the pasta matrix and lost into the cooking medium (Cole, 1991). For example, Sissons and Batey (2003) indicated that lower swelling is related to a reduced leaching of starch contents. In our study, the reduced leaching could be related to a different polymerization extent or a mobility restriction of the components in a matrix with higher dry matter.

Table 3.1. Dry matter (DM), protein, and ash content of cooked pasta (CPi) at the i-th batch number.

Sample	DM (%)	Protein (%)	Ash (%)
CP1	32.76^{b}	4.10^{c}	0.21^{b}
CP2	34.35^{a}	4.35^{b}	0.24^{ab}
CP6	34.33^{a}	4.40^{ab}	0.28^{ab}
CP7	34.46^{a}	4.35^{b}	0.27^{ab}
CP12	35.04^{a}	4.49^{ab}	0.32^{a}
CP13	35.18^{a}	4.41^{ab}	0.30^{ab}

[a]Values followed by the same letter in the same column are not significantly different ($p<0.05$)

Table 3.2. Effect of batch number on cooking loss (CL) and water absorption (WA) of cooked pasta (CPi) at the i-th batch number.

Sample	CL (%)	WA ($g\ g^{-1}$ dm)
CP1	7.41[a]	1.90[a]
CP2	6.36[ab]	1.79[ab]
CP6	5.27[b]	-
CP7	5.17[b]	1.76[b]
CP12	3.78[c]	-
CP13	3.77[c]	1.74[b]

[a]Values followed by the same letter in the same column are not significantly different ($p<0.05$)

The differences in protein network properties were monitored by measuring the level of proteins extractable in dilute SDS containing medium (SDSEP), indicator that decreases with increased polymerization (Hayta & Schofield, 2004). The degree of polymerization was compared for the dry (uncooked) and the cooked spaghetti at the different batches. Approximately 38% of total uncooked pasta proteins was extractable in the SDS containing medium. Cooking of dry pasta to the optimum cooking time decreased the SDSEP levels of pasta to 12.5, 15.6 and 18.2% for cooked pasta at batch 1, 7, and 13, respectively. So, proteins became less extractable as a result of the polymerization during the heat treatment in water (Hayta & Schofield, 2004; Petitot et al., 2009). Even though the SDSEP level of cooked pasta increased with cooking batch number but the results were not statistically different ($p<0.05$), changes in the polymerization extent in the spaghetti strand because of the lower hydration level can not be excluded. Based on our results, we can infer that proteins were retained in the pasta matrix not for a higher polymerization level but most probably for the lower mobility inside the swollen starch-polymerized protein network that prevents some proteins from leaching out. Figure 3.1 shows the elution profile of cooked pasta samples at different batches. The first peak (retention time of 5.5 min) contained glutenin aggregates of very high molecular weight, while the second peak (retention time of 8.4 min) consisted of mainly ω-gliadin. The area in between represented glutenin of lower molecular weight. After ω-gliadin, α- and γ-gliadins eluted. The most striking difference between batches was the peak intensity of albumins and globulins (elution time 9.3-13.0 min). These non-gluten proteins, of which albumins are water extractable, were retained in the pasta matrix upon continuous cooking without crosslinking. Albumins and globulins are monomeric proteins with a molecular weight lower than 25 k (Veraverbeke & Delcour, 2002). Their retention inside the matrix might be related to two factors. The lower plasticizer content leads to higher viscosity and restricted mobility in the matrix resulting in lower possibility for these small molecules to be leached out, further confirming hypothesis of Chapter 2.

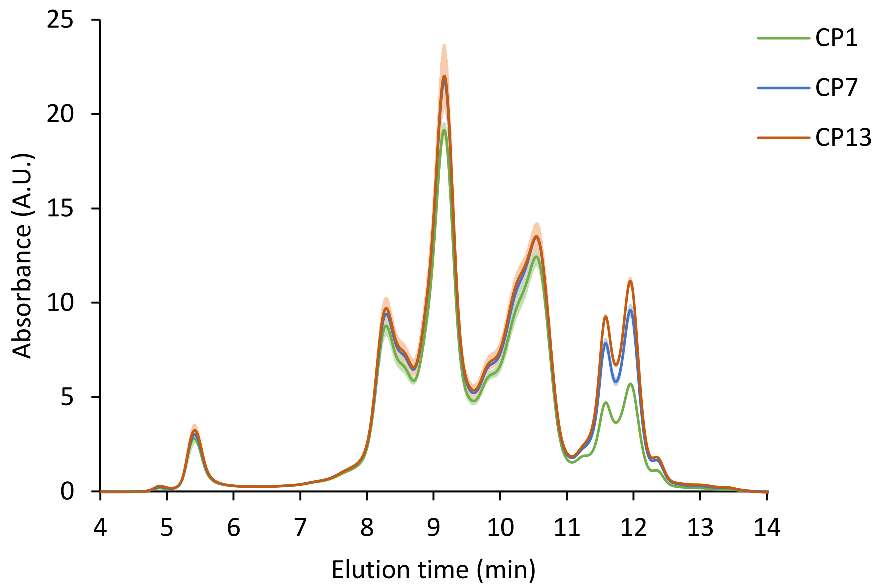


Figure 3.1. SE-HPLC profile of protein extracts in sodium dodecyl sulfate (SDS) buffer of cooked pasta (CPi) at then i-th batch number. A.U., Arbitrary Units. Error bars are displayed with lighter color.

Effect of continuous cooking on cooking water properties

Figure 3.2 shows the dry matter content of the cooking water and supernatant of 13 pasta batches, corresponding to more than 3 hours of continuous cooking in the same cooking water. As expected, it increased upon increased cooking batch number. The dry matter in the cooking water increased by 0.61 vs 0.42 g from batch 1 to 2 and from 12 to 13, respectively; while in the supernatant it increased by 0.52 vs 0.56 g, respectively. The slowing down in dry matter content increase suggests that the cooking water after 13 batches comes closer to its saturation point for solid concentration, as seen after sample evaporation in Chapter 2. In addition, the dry matter increase of the supernatant indicates a higher increase in the water-soluble particles compared to the insoluble and the bigger in size (fragments) ones. Different aspects might play a role here. Pasta fragments are exposed to mechanical and thermal stresses during the subsequent cooking batches (e.g. pasta fragments from batch 1 are cooked for about 3 more hours), which might progressively dissolve parts of these fragments. Indeed, the pasta fragments content, calculated as the dry matter content difference between cooking water and supernatant at the selected batch, increased from batch 1 to 2 (0.25

and 0.38 g, respectively) while decreased from 12 to 13 (2.26 and 2.11 g, respectively). The higher dry matter content might also form a protective layer on the strand surface and edges thanks to the higher viscosity in the cooking water (Figure 2.4), preventing the disintegration during stirring and rolling boil. In addition to the higher dry matter, the continuous cooking procedure led to a pH drop of cooking water and supernatant from alkalinity in batch 1 (8.3 and 8.4, respectively) to acidity in batch 13 (6.5 and 6.6, respectively) (Figure 3.3). This drop is related to the solid concentration increase and tap water (pH 8.2±0.2) addition in between each cooking batch. The drop in pH might explain the technological properties of pasta during cooking (Alary et al., 1980). Acidic pH increases the interactions between protein and gelatinized starch. It has been reported that at an acidic pH, protein molecules are positively charged, and starch molecules are negatively charged. Under these conditions, electrostatic interactions between proteins and gelatinized starch readily occur, enhancing starch-protein interactions (Delcour et al., 2000; Malcolmson & Matsuo, 1993; Sozer & Kaya, 2008; Veraverbeke & Delcour, 2002). In basic media, both protein and starch are negatively charged; therefore, fewer interactions may develop. So, acidic cooking water of the last batches favors starch-protein interactions, preventing the leaching of part of the molecules into the cooking medium.

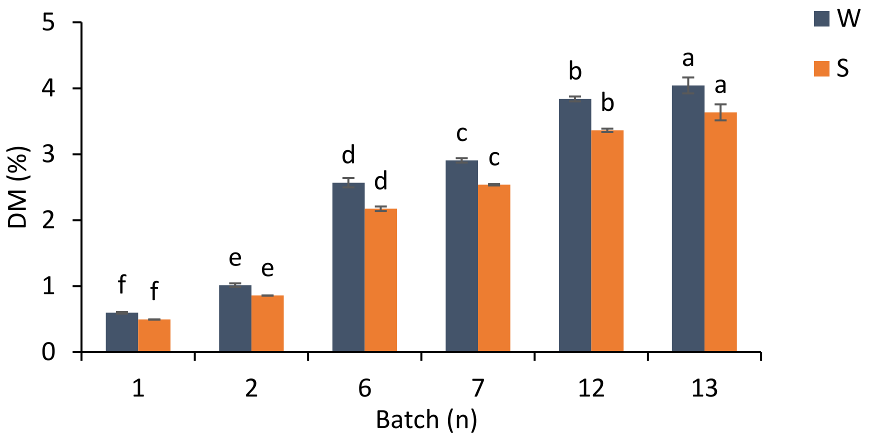


Figure 3.2. Effect of batch number on dry matter (DM) of cooking water (W) and supernatant (S) samples.

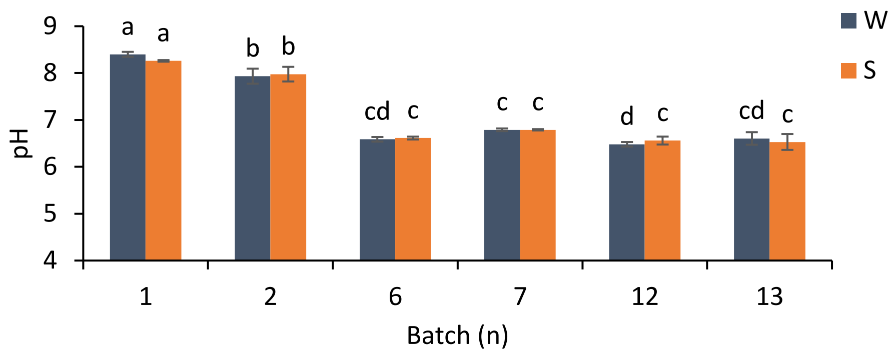


Figure 3.3. Effect of batch number on pH of cooking water (W) and supernatant (S) samples.

Cooking water and supernatant composition is shown in Table 3.3. The values reflect the blocking effect of the accumulation of components inside the cooking water, indeed the enrichment was inversely related to the number of preceding cooking batches. Starch, proteins and minerals gave the water its peculiar characteristics. Starch components, such as amylose and amylopectin short-chain (Matsuo, Malcolmson, Edwards, & Dexter, 1992b), were the most abundant in both suspensions (up to 2.8% for cooking water at batch 13) increasing the viscosity, the turbidity and giving the water an off-flavour of over-cooked flour, as reported by kitchen operators. The protein content also increased upon continuous cooking representing up to 0.27 and 0.18% of cooking water and supernatant samples, respectively. The increase of protein content in cooking water might play a role in the lowering of its pH and the foam formation capability during continuous cooking. Finally, the ash content increase can be related to mineral leaching from the pasta matrix and the tap water addition in between batches. The protein content in the supernatant decreased from 8.3 to 4.9 (%, dm) while the starch content increased from 58.0 to 68.0 (%, dm). It follows that cooking more pasta batches in the same cooking water leads to more pronounced enrichment of leached proteins in the pasta fragments rather than starch. Increasing the dry matter content, the contact between particles gets easier and decreasing the pH their interaction and accumulation get stronger in the suspended fragments. Indeed, the extractability in the SDS containing medium of proteins in cooking water decreased to 53.4% while the one in the supernatant increased to 89.0% (Table 3.3). The SDSEP level reduction in cooking water indicates an increase in the protein cross-linking extent upon continuous cooking while the opposite was for the supernatant samples. These cross-links can form by oxidation of sulfhydryl (SH) groups of cysteine and/or SH-SS interchange reactions but also by β elimination of intramolecular SS bonds (Kaneko & Kitabatake, 1999; Schurer et al., 2007). Both sulfuric and non-sulfuric bonds can decrease the

SDSEP value (Rombouts et al., 2010), which indicated that the continuous cooking procedure enriched the cooking water in polymerizing gluten and non-gluten proteins, mostly aggregating in the pasta fragments.

Table 3.3. Protein, starch and ash content of cooking water (Wi) and supernatant (Si) samples; at the i-th batch number.

Sample	Protein		Starch (%)	Ash (%)
	Total (%)	SDSEP (%)		
W1	0.05^{d}	81.4^{a}	0.36^{c}	0.05^{e}
W2	0.08^{c}	-	-	0.08^{d}
W6	0.20^{b}	-	-	0.15^{c}
W7	0.22^{b}	75.4^{a}	1.89^{b}	0.17^{b}
W12	0.27^{a}	-	-	0.21^{a}
W13	0.26^{a}	53.4^{b}	2.77^{a}	0.22^{a}
S1	0.04^{f}	75.6^{b}	0.28^{c}	0.05^{d}
S2	0.07^{e}	-	-	0.08^{c}
S6	0.14^{d}	-	-	0.16^{b}
S7	0.16^{c}	84.7^{a}	1.62^{b}	0.16^{b}
S12	0.18^{a}	-	-	0.21^{a}
S13	0.18^{b}	89.0^{a}	2.47^{a}	0.20^{a}

[a]Values followed by the same letter in the same column are not significantly different ($p<0.05$)

Figure 3.4 shows the elution profile of cooking water and supernatant samples at different batches. The peak intensity for α- and γ-gliadins (which have the potential to aggregate via covalent bonds and interactions) but also ω-gliadins (only aggregating via non-covalent bonds) increased in the cooking water (Figure 3.4a) but not in the supernatant samples (Figure 3.4b). This supports the earlier hypothesis about aggregation in fragments, which were then separated by centrifugation. Moreover, proteins that are solubilized in supernatant may more easily degrade by being more exposed to the prolonged thermal and mechanical stresses than the ones protected within fragments. Regarding the peak for albumins and globulins, its intensity decreased in both cooking water and supernatant, confirming the increased retention in the spaghetti strand (Figure 3.1) when its surrounding cooking water has been used for more preceding batches. Along with the long time, high temperature and mechanical stress conditions, also the decreasing pH to 6.5 (Figure 3.3) might change the protein extractability profiles. The pH can affect the reactivity of free SH groups that can be exposed during the continuous cooking procedure. In summary, both polymerization and degradation reactions are favored by the long heat treatment at high temperatures and decreasing pH.

Foaming of the cooking water during a single batch, but also over the continuous cooking, is occurring strongly but undesirable. During continuous cooking, foaming leads to cost consuming and safety issues for the establishment and kitchen operators, respectively. Figure 3.5 shows the evolution of FV over time for whipped, cooled cooking water and supernatant samples after cooking batch 1, 7 and 13. The samples from batch 13 produced significantly ($p>0.05$) more foam (96 mL) than batch 7 and 1 (80 and 48 ml, respectively). Foams from batch 7 and 13 were quite stable, with remaining FVs being 60 and 70 ml, respectively, after 60 min. Batch 1 foam was relatively unstable, resulting in a low FV of 15 ml after 60 min. This higher stability of foam over continuous cooking provides the scientific proof for the empirical observations by kitchen operators, even though the foam production method was different (whipping versus rolling boil). Interestingly, there were no statistical differences ($p<0.05$) in FV over time between cooking water and supernatant foams at the same batch, even though the protein content of cooking water was higher than that of supernatant (Table 3.3). This seems counterintuitive, as an increase in concentration of surface-active constituents would be expected to be accompanied by improved foaming characteristics. These results suggest that the suspended, larger particles in the cooking water did not provide further proteins for foam generation. They did not impair the foaming of bulk proteins, probably being expulsed out of the films during foam formation (Fameau & Salonen, 2014). As no negative effect by the larger particles was observed, it is thus fair to state that they act as inert particles for foam formation and stabilization. In addition to protein content, the decrease in pH might also minimize the electrostatic repulsion leading to a rapid protein adsorption to the interface and improving the foaming properties in both cooking water and supernatant (Foegeding, Luck, & Davis, 2006).

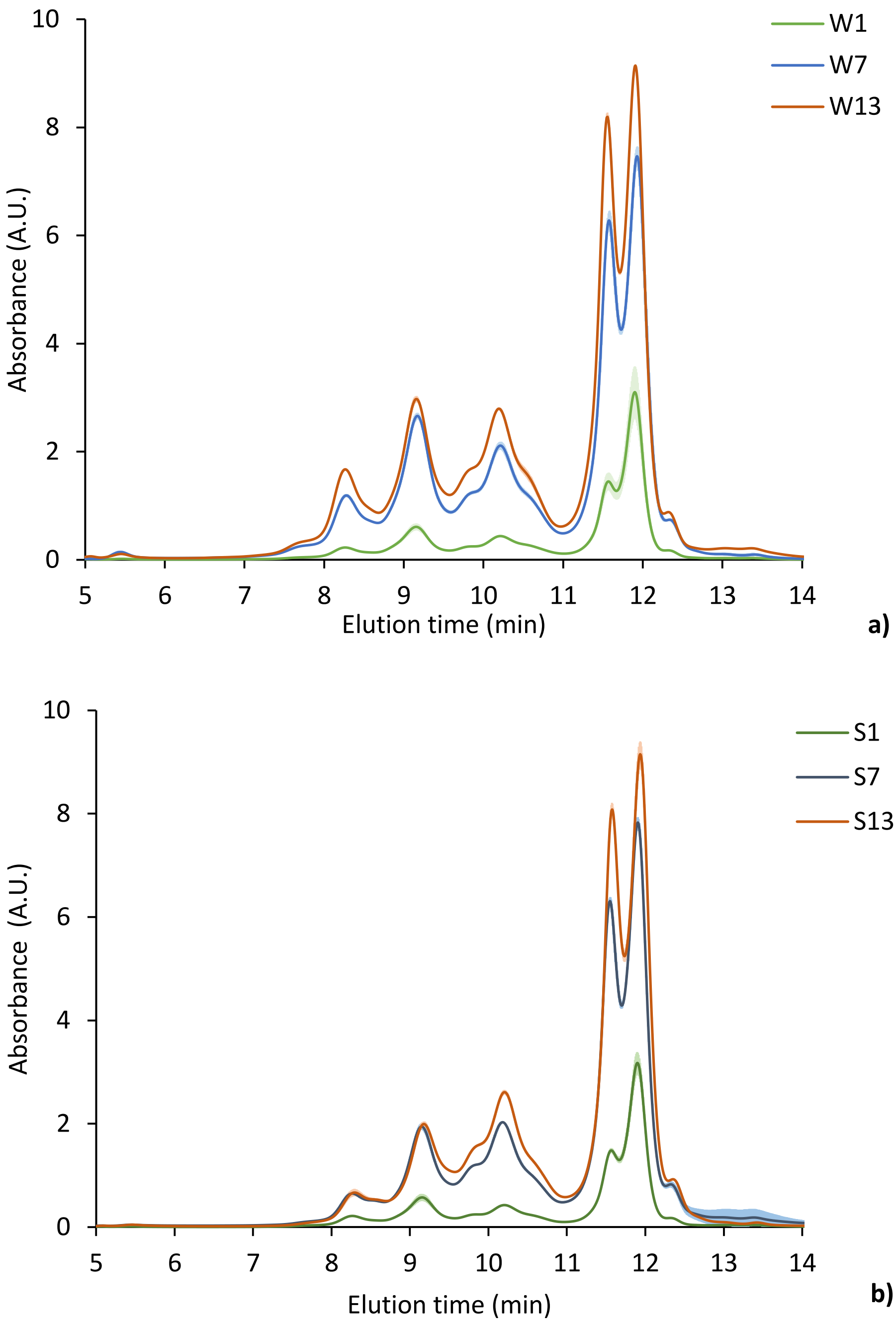


Figure 3.4. SE-HPLC profile of protein extracts in sodium dodecyl sulfate (SDS) buffer: **a)** cooking water (Wi); **b)** Supernatant (Si); at the i-th batch number. A.U., Arbitrary Units. Error bars are displayed with lighter color.

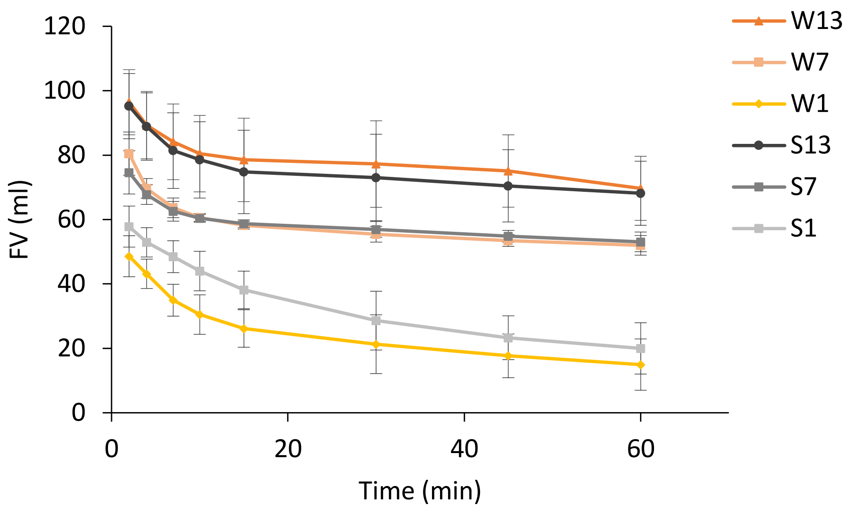


Figure 3.5. Foam volume (FV) as a function of time of cooking water (Wi) and supernatant (Si) samples, at the i-th batch number. Error bars represent the deviation from the mean for single measurements of three separate experiments.

Effect of solid content and pH on the leaching behavior of pasta

Changes in dry matter content and pH during the continuous cooking procedure were demonstrated to be important factors in determining the leaching behavior of pasta and foaming properties of cooking water. To discern the effect of dry matter content increase upon continuous cooking and investigate the role of pH and minerals in water, single pasta batches were cooked in tap water, distilled water and tap water at the lowest experimental pH (pH of batch 13). After boiling and cooling down to get rid of carbonated water, the pH of tap water was 8.2. Interestingly, adjusted pH and distilled water had similar mild-acidic pH close to 7 (6.8 and 6.7, respectively) despite the different mineral content. After pasta cooking, the pH was 8.4, 8.0 and 5.9, respectively (Table 3.4). Thus, the pH increased during the continuous cooking process to alkalinity for tap and adjusted pH water, representing water samples with minerals, and it further decreased to acidity in the case of distilled water. This change in pH is probably related to solid leaching from spaghetti strands in cooking water. The dry matter content in cooking water was the lowest for distilled water followed by tap and adjusted pH water and the same was found for protein content (Table 3.5).

The technological properties of pasta were not affected by the different cooking water characteristics as shown in Table 3.5. In particular, the cooking loss and the water absorption were not statistically different in the different cooking water. This indicates that a pH from 5.9 to 8.4 and the mineral content of the tap water here studied did not hinder pasta hydration capability and consequent loss of components during cooking. This result is in contrast with Alary et al. (1979), who reported reduced cooking loss when pH is adjusted to 6. Cooking in distilled water led to a decrease in pH and lower solid leaching, which supports the observation by Abecassis, Alary, & Kobrehel (1981).

However, some differences were found on the final composition of pasta samples (Table 3.5). Solid and protein contents of pasta cooked in distilled water were the highest while the ones of pasta cooked in tap and adjusted pH the lowest. Alkaline pH of tap and adjusted pH determines few interactions during cooking and lower retention of proteins (Sozer & Kaya, 2008). This means that not only pH but also minerals in adjusted water play an important role during cooking. Sodium (Na^+), calcium (Ca^{2+}) and aluminum (Al^{3+}) ions are in tap water the most abundant monovalent, divalent and trivalent cations, respectively (De Watergroep, 2019). Thus, tap and adjusted pH waters that were alkaline and contained calcium and magnesium ions weakened the protein-starch film at the pasta surface leading to lower retention of proteins. The ions at the surface acted as a glue to bond pasta surfaces to each other determining the perceived stickiness by kitchen operators. This adds another factor to consider during continuous cooking of pasta in the same cooking water, in addition to dry matter, so solid content, and lower pH from the preceding batches.

Table 3.4. Effect of water condition on dry matter (DM), pH and composition of cooking water.

Water condition	DM (%)	pH	Protein (% wb)	Ash (% wb)
Tap	0.59^{ab}	8.4^{a}	0.05^{a}	0.05^{b}
Adjusted pH	0.65^{a}	8.0^{b}	0.05^{a}	0.07^{a}
Distilled	0.52^{b}	5.9^{c}	0.04^{b}	0.03^{c}

[a]Values followed by the same letter in the same column are not significantly different ($p<0.05$)

Table 3.5. Effect of water condition on dry matter (DM), cooking loss (CL), water absorption (WA) and composition of cooked pasta.

Water condition	DM (%)	CL (%)	WA ($g\ g^{-1}$ dm)	Protein (% wb)	Ash (% wb)
Tap	32.76^{b}	7.41^{a}	1.90^{a}	4.10^{b}	0.21^{a}
Adjusted pH	32.87^{b}	7.64^{a}	1.84^{a}	4.22^{b}	0.22^{a}
Distilled	34.72^{a}	6.58^{a}	1.83^{a}	4.43^{a}	0.20^{a}

[a]Values followed by the same letter in the same column are not significantly different ($p<0.05$)

CONCLUSIONS

The professional continuous cooking was proved to have a significant impact on cooking water properties and spaghetti cooking quality. Presence of leached solids in the cooking water from preceding batches limited water uptake, which resulted in lower cooking losses. This influenced particularly protein leaching, which increased in content from 4.10 to 4.41%. Of these proteins, albumins and globulins were found to be the most retained ones. Increasing the cooking batch number led to a drop of cooking water pH from alkalinity (8.3) to acidity (6.5). Consequently, leached proteins concentrated more in the pasta fragments of cooking water than starch. Foaming stability was increased over continuous cooking, but the accumulated proteins in pasta fragments did not aid foam stability by being expulsed out of the films during foam formation. Cooking in different pH and without minerals was investigated with the findings that the type of water used for cooking influenced pasta composition but not cooking loss and water absorption.

Chapter

4

Effect of US and HPH on cooking water properties of continuously cooked spaghetti

INTRODUCTION

The continuous cooking procedure in pasta cookers leads to extensive leaching of solids from the cooked pasta that affects cooking water properties, particularly viscosity, color, and foaming capacity of cooking water. These represent relevant issues affecting the working life of kitchen operators, along with time, energy and cost wastes relevant to the food service establishment business.

Among the different commercial uses of power US (Martini et al., 2010), they have been explored for the ultrasound-induced partial or total depolymerization of natural polysaccharides. The depolymerization process occurs through the effects of cavitation and can involve two possible mechanisms: mechanical degradation of the polymer from collapsed cavitation bubble, and chemical degradation as a result of the chemical reaction between the polymer and hydroxyl radicals (Grönroos, Pirkonen, & Ruppert, 2004). Biopolymer structure would be modified by reducing polymer size as well as inducing conformational changes. As a consequence, novel inter-particle interactions accompanied by a change of the rheological properties could be obtained (Seshadri et al., 2003). The ultrasonic process has been confirmed to be applicable to many kinds of starches (corn, potato, tapioca, and sweet potato) and polysaccharides (Iida, Tuziuti, Yasui, Towata, & Kozuka, 2008). BeMiller & Huber (2015) reported depolymerization of the starch polysaccharide molecules and large and fairly rapid decreases in starch paste viscosity after ultrasonic treatment. The viscosity of starch solution after gelatinization was reduced by about two orders of magnitude by the ultrasound applied for 30 min on 5% starch slurry (Iida et al., 2008).

During HPH, high pressure gradients and high local velocities of liquid layers in the vicinity of cavitation bubbles are capable of breaking the chains of polymers by disrupting covalent bonds (Dumay et al., 2013). As in US, some of the OH radicals and H atoms generated from water decomposition can react with solute molecules causing polymer degradation (Freudig, Tesch, & Schubert, 2003). Polymers in the hot interfacial regions between the cavitation bubble and the surrounding liquid may also be pyrolyzed (Czechowska-Biskup et al., 2005). Liquids with different properties can thus be obtained. Several researchers studied the degradation or disruption of polymers caused by HPH, in pure solution or emulsion. High shear, turbulence forces, and cavitation produced the reduction of the thickening and stabilizing properties of xanthan, the molecular weight and apparent viscosities of methylcellulose, and the solution viscosities of large food polymers by partial depolymerization (Floury et al., 2002; Kasaai et al., 2003; Lagoueyte & Paquin, 1998; Modig et al., 2006). HPH can be used to deagglomerate rice starch-protein aggregates in presence of water (Guraya & James, 2002). In industry, HPH has been used as a promising technology for reducing the viscosity of

starch pastes that causes problems related to transport and processing (Che et al., 2009).
Modification of biopolymers physical properties are reported to highly depend on matrix characteristics and HPH and US intensity, that is, pressure level and number of passes applied during HPH, or ultrasonication time (Lopez-Sanchez et al., 2011; Vercet et al., 2002). To our knowledge, HPH and US performances in the attempt to retain the properties of cooking water obtained from continuously cooked spaghetti are hardly comparable due to scarce information. Indeed, limited if any information is available on the molecular degradation of pasta cooking water components. Moreover, data on the role of leached solids concentration in affecting changes in physical properties as induced by HPH and US are absent.

AIM OF THE STUDY

The aim of the present study was to investigate the use of HPH and US for modifying some physical properties of cooking water obtained from continuously cooked spaghetti. The final purpose was to obtain cooking water with fresh-like properties, especially turbidity and rheological properties. To this purpose, cooking water at different batches was subjected to HPH and US for increasing pressure levels or treatment time periods, respectively, and the changes in some physical properties were studied. Finally, to steer food service industry choice on the most feasible technology, theoretical considerations in collaboration with engineers working within the GR&D department of Electrolux Professional S.p.A were elaborated.

MATERIALS AND METHODS

Materials

Durum wheat spaghetti (2 mm diameter) was purchased from the same specialized supplier to the food service sector (Marr, Italy) as in Chapter 2.

Cooking procedure

The laboratory scale continuous cooking procedure was carried out as explained in Chapter 2 (page 28). Cooking water samples were collected at batch 1, 7 and 13.

Ultrasound (US) treatment of cooking water

Cooking water was treated with an ultrasonic processor (Hielscher Ultrasonics GmbH, mod. UP400S, Teltow, Germany) with a titanium horn tip diameter of 22 mm. The instrument operated at constant ultrasound amplitude, power and frequency of 100 µm, 400 W and 24 kHz, respectively. Right following the collection, cooking water samples were divided in two homogeneous aliquots and treated, then recombined. Samples were introduced into 400 mL capacity (110 mm height, 60 mm internal diameter) glass vessels with a circulating mixture of water and glycol. The tip of the sonicator horn was placed in the center of the sample, with an immersion depth in the fluid of 70 mm. The temperature was recorded as a function of time using a copper constantan thermocouple probe (Ellab, Denmark), connected to a data-logger (CHY 502A1, Tersid, Milano, Italy). The thermocouple tip was immersed (80 mm) in the sample halfway between the dispersion center and the inside wall of the vessel. In order to minimize water evaporation during sonication, the vessel was closed with a Plexiglas® lid fitted with holes allowing the horn and thermocouple probe to be placed at the desired position in the cooking water. Cooking water samples and distilled water were treated without temperature control for 20 min. Treatment of samples was carried out for 5 and 20 min. During the treatment, the temperature was controlled using a cryostatic system (Thermo Scientific Haake PC200 A25) set at 80 °C, value as much close to the cooking temperature as possible. Following the treatment, the samples were cooled down in a water bath (15±5 °C) for 30 min under gentle magnetic stirring before analysis.

High pressure homogenization (HPH) treatment of cooking water

A continuous lab-scale high-pressure homogenizer (Panda Plus 2000, GEA Niro Soavi, Parma, Italy) supplied with two Re+ type tungsten carbide homogenization valves with a flow rate of 10 L/h was used to treat cooking water. The first valve was the actual homogenization stage and was set at increasing pressure of 20, 40, 60, 80 and 100 MPa. The second valve was set at the constant value of 5 MPa. Temperature was recorded before and after the treatments. Following the treatment, the samples were cooled down in a water bath (15±5 °C) for 30 min under gentle magnetic stirring before analysis.

Determinations

Solid content

The cooking water was weighed, placed in an air oven at 105 °C and evaporated until a constant weight was reached. The solid content (%) of cooking water was the percentage of solid substance in the cooking water.

Color analysis

Color analysis was carried out using a tristimulus colorimeter (Chromameter-2 Reflectance, Minolta, Osaka, Japan) equipped with a CR-300 measuring head. The instrument was standardized against a white tile before measurements. Color was expressed in L*, a* and b* scale parameters.

Turbidity

The turbidity was determined by measuring the absorbance at 600 nm and room temperature with a UV–visible spectrophotometer (UV-2501PC, Shimadzu, Japan). Samples were kept under gentle magnetic stirring right before the analysis.

Images

Cooking water images were captured using a digital camera (Canon EOS 550D, Tokyo, Japan) mounted on an adjustable stand positioned 30 cm in front of a black cardboard base where the sample was placed. Light was provided by two 46 W frosted photographic floodlights in a position allowing minimum shadow and glare. Images were saved in the JPEG (5184x3456 pixels) file format.

Rheological properties

The rheological measurements were carried out using a RS6000 Rheometer (Thermo Scientific RheoStress, Haake, Germany), equipped with a coaxial cylinder geometry (CCB25 Din) and a Peltier system for temperature control, as the one used in Chapter 2. Measurements were conducted at 25 and 80±0.2 °C after HPH treatment, and 80±0.2 °C after US treatment. Before any measurements were taken, samples rested for 5 min at the selected temperature after loading. Steady shear measurements (flow curves) were performed over a shear rate range from 3 to 100 s^{-1} and the power law model was used to fit the flow data (Equation 2.2).

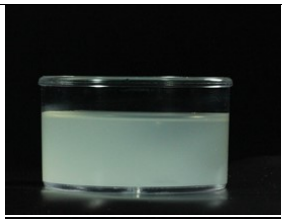
Statistical analysis

All experiments were performed in triplicate unless otherwise mentioned. Statistical differences in solid content, absorbance and temperature upon treatment of cooking water were determined by one-way analysis of variance (ANOVA) and Tukey's comparison test ($p<0.05$). The goodness-of-fit was evaluated based on statistical parameters of fitting (coefficient of determination, R^2 and standard error). The statistical software, R (The R foundation for statistics, v. 3.0.3), was used for the analysis.

RESULTS AND DISCUSSION

Cooking water was obtained performing the continuous cooking procedure of spaghetti on laboratory scale. Table 4.1 shows the macroscopic images of cooking water at batch 1, 7 and 13. At batch 1 cooking water appeared clear while at batch 13 particularly turbid, as indeed reported by kitchen operators. Differences in water appearance, mainly relevant to color, can be observed particularly between the batch 1 and batch 7. The appearance of cooking water is an unpleasant fact for kitchen operators, who relate this change to viscosity and off-flavor and empirically use it to choose whether to empty the well replacing the volume of water or not. To quantify these changes, samples were analyzed for their color and turbidity. Determination of the color parameters of the cooking water showed that with increasing the batch number, lightness (L*) was constant until batch 10, while increased afterwards (Table 4.1). By contrast, redness (a*) and yellowness (b*) decreased upon continuous cooking. In other words, the greenness and blueness increased.

Table 4.1. Lightness (L*), color parameters (a* and b*) and images of cooking water as a function of batch number.

Batch (n)	L*	Color parameters		Images
		a*	b*	
1	27.26±0.68	4.45±0.33	-4.80±0.39	
7	26.21±0.86	4.43±0.26	-7.58±0.16	
13	30.22±1.00	2.68±0.29	-7.87±0.23	

Effect of US on cooking water properties

In order to study the effect of ultrasound processing with *in situ* generated heat, sample temperature was left to rise during the ultrasound process due to heat dissipation. Trials without temperature control were performed in continuous mode. Figure 4.1 shows the time-temperature profiles during ultrasound processing of cooking water of batch 1 and 13, and distilled water, without temperature control. As expected, temperature increased during treatments, reaching approximately 90 °C after 15 min of US. This increase approached a plateau which was not achieved in this time range. Batch 13 had constantly higher temperature than batch 1, and distilled water that was related to solid content. Effective sonication depends upon balance between cavitation and temperature, when the latter is lower the former is favored (Ogutu, 2015). US were applied on cooking water at 80 °C, trying to find a compromise between the operating temperature in the real environment (boiling) and the reduction of volume loss by evaporation during treatment.

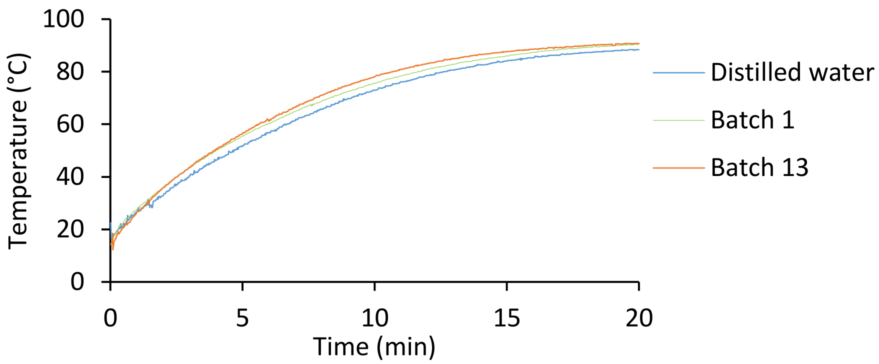


Figure 4.1. Time-temperature profiles of cooking water at batch 1 and 13, and distilled water, during ultrasound provided under uncontrolled temperature regime.

Figure 4.2 shows the solid content of batch 1, 7 and 13 as control samples, i.e. untreated, and US treated for 5 and 20 min. As expected, solid content increased upon continuous cooking for both treated and untreated samples, ranging from 0.43 to 3.79%, confirming the results of Chapter 2 and 3. When the solid content was lower, i.e. batch 1 and 7, ultrasonic treatment led to significant higher solid concentration already after 5 min of processing. This means that the application of ultrasounds at 80 °C, even though all precautions were taken, led to water loss during treatment and thus slightly increased the resulting sample concentration. By contrast, ultrasonically treated samples at batch 13 did not show differences compared to the untreated one. The particles in suspension might hinder a significant evaporation during treatment resulting in samples with similar concentration. Sample concentration was thought to be related to sample turbidity and thus reduced cooking water quality. Higher absorbance implies a more turbid water. Sample turbidity is shown as a function of batch number in Figure 4.3. Upon continuous cooking, the increase in batch number and thus the increase in solid content, resulted in an increase in the absorbance from 0.09 to 1.04. After US treatment, sample absorbance increased for batch 1 and batch 7 compared to untreated samples, and specifically, increasing the time of treatment from 5 to 20 min led to higher absorbance for batch 7. Thus, the increase of solid concentration after US treatment led to higher absorbances.

For batch 13, instead, similar solid content did not result in similar absorbances and after 20 min of US treatment the turbidity increased. These data suggest that longer application time result in a more turbid material for a concentration factor but also particle dimensions. It is known that the effect of US on the turbidity of the sample depends on its solid content (Kardos & Luche, 2001; Lorimer, Mason, Cuthbert, & Brookfield, 1995). Then, the higher treatment time had a homogenization effect on cooking water components and thus reduced the particle size and pasta fragment dimensions. Smaller particles more likely stayed in suspension for longer time leading to higher absorbances. In addition, this result is in accordance with previous research by Ashokkumar et al. (2009) who showed that whey protein aggregate size reduced significantly after US. US would be able to disrupt protein–protein interactions, which at low concentration are mainly hydrophobic and ionic, and can be more easily disrupted than interactions like disulfide bonds that occur at higher protein concentrations. The absorbance is also a function of the amount of starch components in the cooking water which refract light; the more starch components there are, the higher absorbance is.

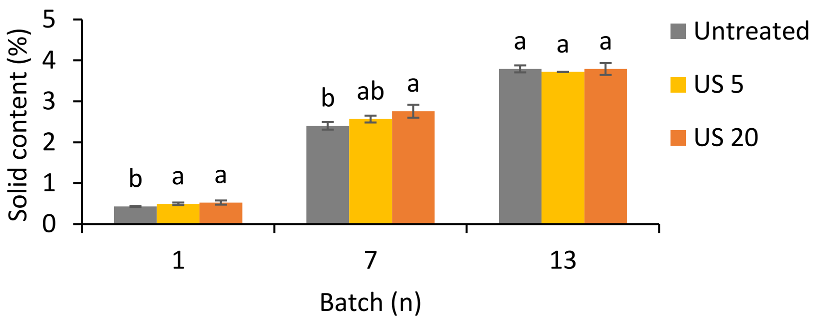


Figure 4.2. Solid content of cooking water samples untreated and after US treatment for 5 (US 5) and 20 (US 20) min, as a function of batch number.

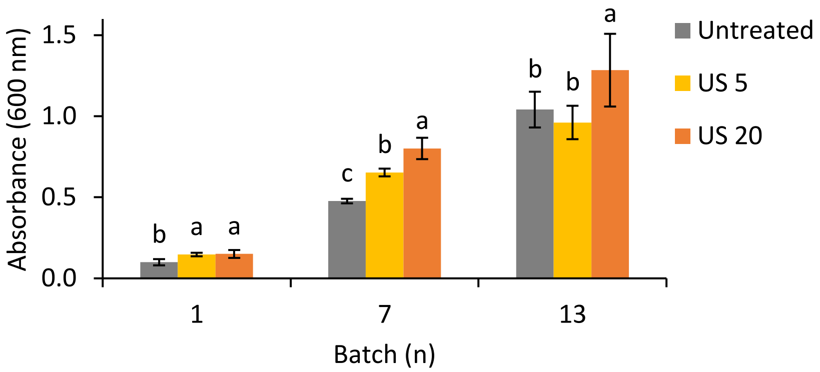
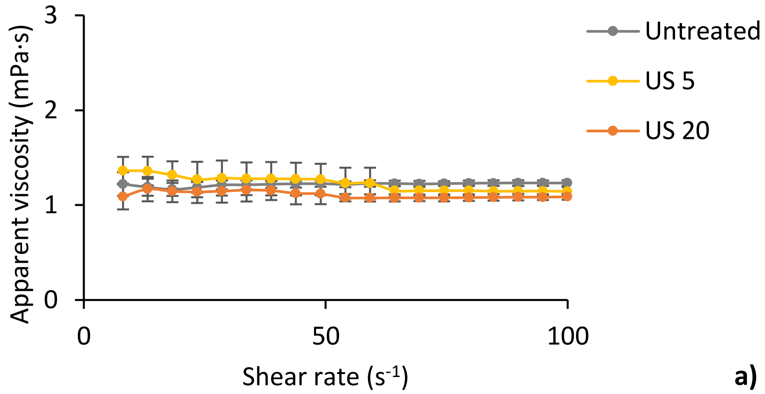


Figure 4.3. Absorbance of cooking water samples untreated and after US treatment for 5 (US 5) and 20 (US 20) min, as a function of batch number.

Along with the increase in turbidity, kitchen operators indicated also an increase in viscosity of cooking water upon continuous cooking. Flow properties were investigated at room (25 °C) and at the closest temperature to boiling point (80 °C), simulating the condition of use and possible application of US technology on industrial scale. Figure 4.4a and Figure 4.4b show the flow curves of cooking water of batch 1 at 25 and 80 °C, respectively. Flow curves of the dispersions showed a Newtonian behaviour and this because of the low solid content, at both temperatures. Figure 4.5a and Figure 4.5b show the flow curves of cooking water of batch 7 at 25 and 80 °C, respectively. In accordance with Che et al. (2008), flow curves of the dispersions showed shear thinning behaviour under steady shear flow for the untreated and US treated for 20 min samples, and the same trend was observed for flow curves at 80 °C. At batch 13, the untreated samples showed higher viscosity curves than both the US 5 and 20 ones, at both temperatures (25 and 80°C, Figure 4.6a and Figure 4.6b, respectively).
This flow behaviour was described by a power law model (Equation 2.2) and the corresponding parameters are summarized in Table 4.2. Flow index (n) values of 0.975–1.016 for batch 1 at 25 °C are consistent with a Newtonian behaviour, while after 5 min US treatment and higher batch number shear thinning behaviour was observed. Batch 7 and 13 samples showed a stronger shear thinning behaviour when US treated for 20 min, at both temperatures, and this could be related to higher solid content. At 25 °C, the consistency index K decreased from 8.731 to 3.553 and from 54.268 to 45.847 when treating the sample for 5 min for batch 7 and 13, respectively. K increased when prolonging the processing time to 20 min. This trend was confirmed at 80 °C. The increase in consistency index upon a longer US treatment, at batch 7 and 13, could be related to the higher solid content of such samples that results in an increased restriction of molecular motion due to entanglements between polymer chains (Karazhiyan et al., 2009; Lapasin & Pricl, 1995). The

untreated samples showed higher consistency values compared to the US treated for 5 min ones, even though the former had a lower solid content compared to the latter. By contrast, a higher solid content generally causes an increase in the viscosity (Bhattacharya, Bhat, & Raghuveer, 1992; Maskan, 2000). So, the solid content could not be directly related to the rheological behaviour, since similar solid content did not result in similar behaviour. The flow behaviour is usually influenced by the concentration and temperature, but here small differences in concentration were not reflected in differences in rheological properties. Therefore, the reduction in consistency index could be related to an effect of US treatment on aggregates and polymer chains in the first 5 min of treatment. Both generation of OH radicals and mechanical effects can be responsible for the chain cleavage, with consequent reductions in viscosities and consistency coefficients. However, decreases in viscosity during ultrasonic treatment have also been attributed to disintegration of supermolecular aggregates (Seguchi, Higasa, & Mori, 1994). Only long chains are vulnerable to breakage by the action of hydrodynamic forces, while chains below some limiting critical size cannot be degraded (Chen & Chen, 2000). This is achieved after 5 min.

From a food service point of view, the higher the batch number the more important the effect of US on viscosity is. In addition, the reduction of consistency index was obtained after 5 min of treatment while an increase was observed prolonging the treatment time. This is a promising result in light of an industrial implementation of such a technology, in terms of food service operating time and costs, as discussed with engineers.



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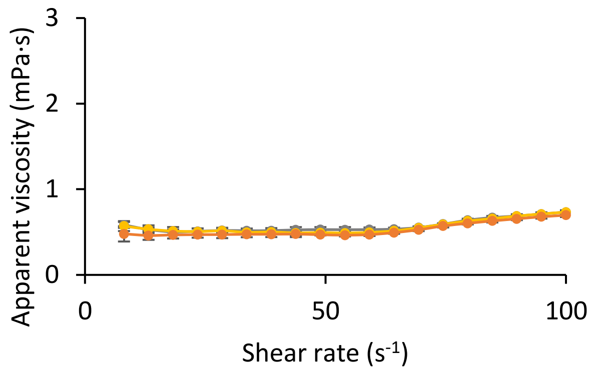
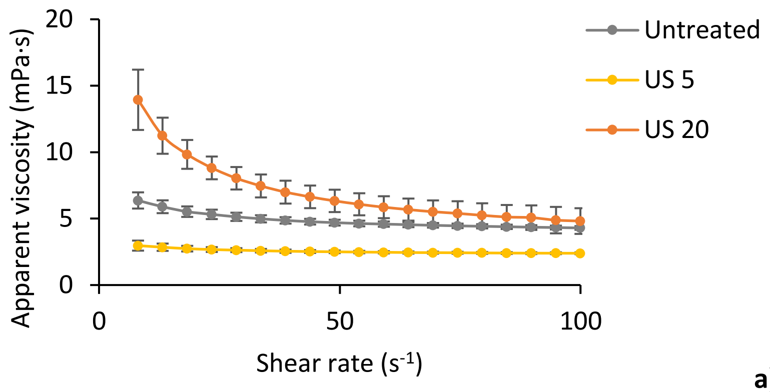


b)

Figure 4.4. Apparent viscosity as a function of shear rate for batch 1 untreated and treated samples for 5 (US 5) and 20 (US 20) min at **a)** 25 °C and **b)** 80 °C.



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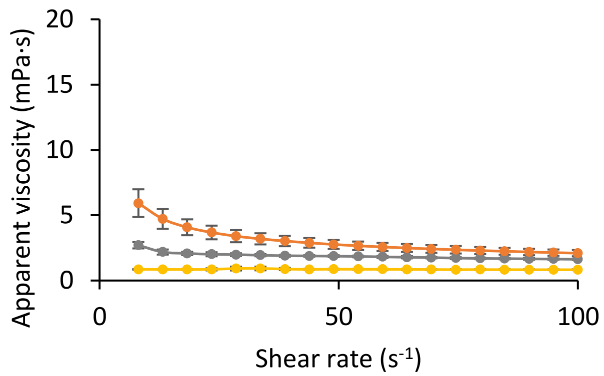
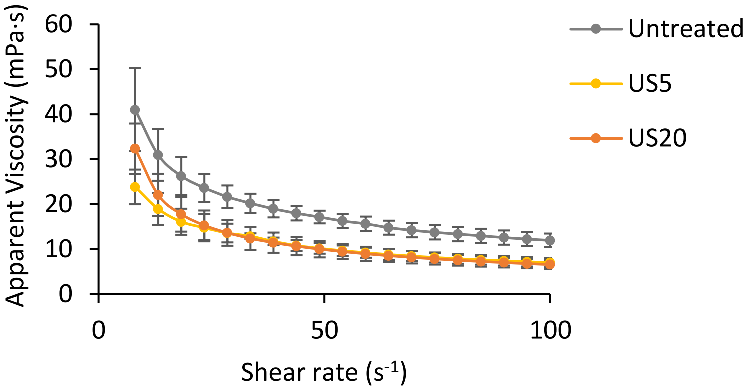


b)

Figure 4.5. Apparent viscosity as a function of shear rate for batch 7 untreated and treated samples for 5 (US 5) and 20 (US 20) min at **a)** 25 °C and **b)** 80 °C.



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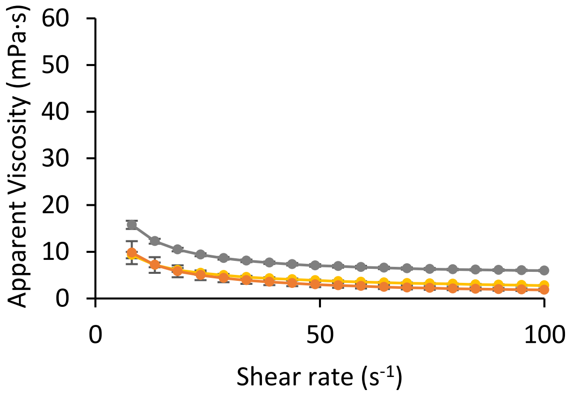


b)

Figure 4.6. Apparent viscosity as a function of shear rate for batch 13 untreated and treated samples for 5 (US 5) and 20 (US 20) min at **a)** 25 °C and **b)** 80 °C.

Table 4.2. Power law parameters for cooking water at different batch number (untreated, NT) and ultrasonically treated for different times.

Temperature (°C)	Batch (n)	Time (min)	n	K (mPa·s^n)	R^2
25	1	NT	1.016±0.029	1.154±0.170	0.999
		5	0.921±0.040	1.683±0.388	0.997
		20	0.975±0.054	1.245±0.334	0.998
	7	NT	0.845±0.026	8.731±1.244	0.999
		5	0.915±0.041	3.553±0.743	1.000
		20	0.573±0.041	33.729±4.112	0.996
	13	NT	0.627±0.021	54.268±4.015	0.994
		5	0.509±0.014	45.847±3.342	0.968
		20	0.394±0.031	72.169±5.857	0.987
80	1	NT	1.103±0.037	0.388±0.062	0.983
		5	0.850±0.098	0.385±0.071	0.977
		20	1.148±0.054	0.305±0.085	0.983
	7	NT	0.834±0.045	2.818±1.046	0.997
		5	0.982±0.019	0.916±0.105	0.996
		20	0.599±0.024	13.360±2.929	0.999
	13	NT	0.627±0.012	31.344±2.105	0.991
		5	0.527±0.023	24.511±3.204	0.999
		20	0.327±0.039	42.052±4.682	0.996

Power law parameters: K, consistency coefficient; n, flow behaviour index; means ± standard deviation

Effect of HPH on cooking water properties

Cooking water obtained from continuously cooked spaghetti was subjected to HPH treatment in the attempt to retain fresh-like physical properties. Before and after HPH treatment at each batch, samples did not show any differences in solid content (data not shown) contrary to US treatment. The effect of treatment on sample temperature as a function of pressure and batch number is reported in Figure 4.7. A higher batch number resulted in slightly higher temperature at the outlet of the homogenizer, for all the pressure tested. Increasing the pressure level at each batch number significantly ($p>0.05$) increased the temperature of cooking water. Thus, a higher solid content and higher pressure resulted in higher temperature of the samples. Linear relationships with high coefficients of determination ($R^2>0.95$) are suitable for describing the relationship between the homogenizing pressure and the temperatures of homogenized cooking water. The temperatures of homogenized cooking water increased linearly with the increasing of homogenizing pressure. The slopes of the lines indicating the dependence of temperature on the homogenizing pressure were 0.18, 0.19 and 0.15 °C/MPa for batch 1, 7 and 13, respectively. These data confirmed a linear relationship of temperature with increasing homogenizing pressure for starch suspensions at 2%, with a rate of 0.2 °C/MPa, as reported by Che et al. (2009). The strong warming up of the fluid is due to viscous stress caused by high velocity of the cooking water flow, friction between the water and the valve, and cavitation (Floury et al., 2004). The linear increase in temperature has been widely reported with different values for the extent of temperature rise with homogenizing pressure (Brookman, 1974; Desrumaux & Marcand, 2002; Hayes & Kelly, 2003). From a pasta cooker application perspective, the increase in temperature does not represent a great issue but it should be taken into account, even more so if cooking water has to be treated at high temperatures during the continuous cooking procedure.

Sample turbidity is shown as a function of batch number in Figure 4.8. Upon continuous cooking, the absorbance of the samples increased at all the pressure level tested. Particularly, the absorbance of untreated and treated at 20 MPa samples increased with batch number from 0.1 to 0.9 and 0.1 to 0.5, respectively. The increase in turbidity upon continuous cooking is related to solid content in cooking water. The effect of HPH on absorbance was the significant reduction of the value for all the batches. Then, increasing the pressure did not result in a further decrease in turbidity. This means that the untreated components in cooking water were all disintegrated during homogenization at 20 MPa promoting cooking water clarity. Consequently, further increase of homogenizing pressure could not develop more transparent cooking water any longer. Similar findings were reported treating pre-gelatinized and cooled starch pastes (Che et al., 2009). This is a promising achievement in light of an industrial application of the technology, as again reported by engineers.

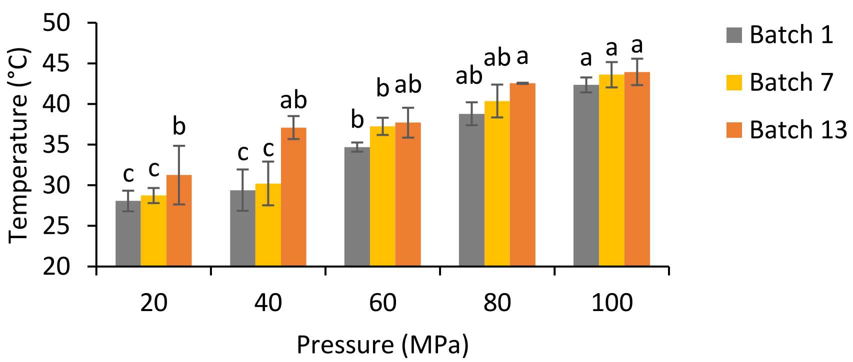


Figure 4.7. Temperature of cooking water of batch 1, 7 and 13 after HPH treatment as a function of pressure.

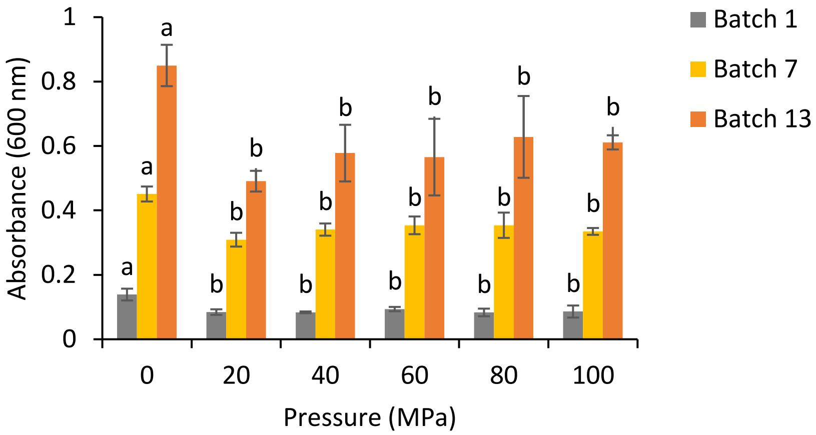
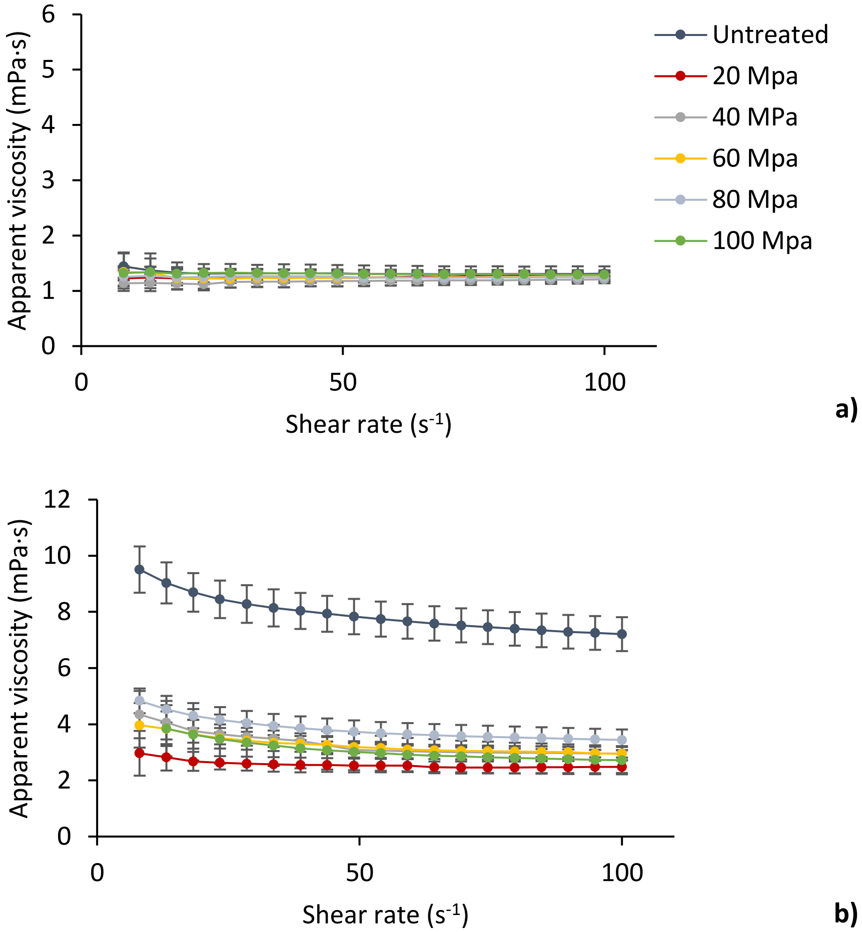
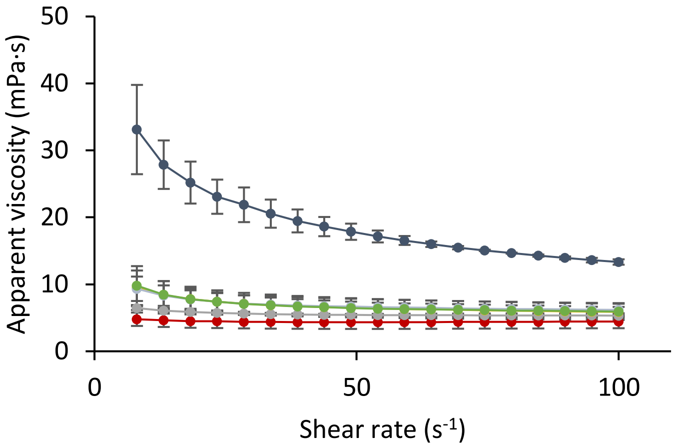


Figure 4.8. Absorbance of batch 1, 7 and 13 untreated (indicated by 0 MPa) and after HPH treatment as a function of pressure.

Flow properties of cooking water after HPH treatment were investigated at room temperature (25 °C). As can be observed from Figure 4.9, the apparent viscosities of non-homogenized cooking water decreased with the increase of the shear rate suggesting that these suspensions exhibit shear-thinning or pseudoplastic behavior. The flow behaviour indices of non-homogenized cooking water are less than unity (Table 4.3). Applying a homogenizing pressure of 20 MPa, the flow behaviour indices approached unity indicating that cooking water samples at all batches can be regarded as Newtonian fluids. The apparent viscosities of these cooking waters were independent of the shear rate in the tested shear rate range. The consistency indices of the cooking water were reduced with the application of the minimum homogenizing pressure. When pressure was increased beyond 20 MPa, the indices increased (see Figure 4.9, and Table 4.3). The flow behaviours of cooking water are affected by the rheological properties of the pasta leached components, i.e. amylose and proteins (mainly albumins and globulins, see Chapter 3), in continuous phase. A strong interaction between aggregated components restricts the flow of starch-protein-water system resulting in high apparent viscosity (Rao & Tattiyakul, 1999). HPH treatment possibly act on these interactions.

At batch 1, the solid content was too low for a significant effect on apparent viscosity (Figure 4.9a). Instead, the HPH processing had a significant effect in the case of batch 7 and 13 (Figure 4.9b and c, respectively). During homogenization at 20 MPa, the aggregates of starch-proteins and pasta fragments were all disintegrated by the intense mechanical forces involved in the process leading to remarkable decrease in apparent viscosities and transformation from shear-thinning to Newtonian behaviour for these cooking water samples. The rheology depends on solid content and upon the molecular weight of components. Thus, the degradation of components arose from HPH possibly contributed to the reductions in the apparent viscosities of the homogenized components. Czechowska-Biskup et al. (2005) theorized that there is a minimum chain length limiting the degradation process and so it is reasonable to assume that there is a definite minimum apparent viscosity corresponding to the minimum chain length, given a certain concentration. So, the polymer chains approached the minimum chain length already at the minimum applied pressure. This result, as in the case of US processing, is an encouraging result from an industrial application point of view, allowing to apply the minimum pressure for obtaining better results.





c)

Figure 4.9. Apparent viscosity as a function of shear rate for untreated samples and treated at increasing pressure levels at **a)** batch 1, **b)** batch 7, **c)** batch 13.

Table 4.3. Power law parameters for cooking water at different batch number (non homogenized, NH) and treated under different pressure levels.

Batch (n)	Pressure (MPa)	n	K (mPa·s^n)	R^2
1	NH	0.963±0.028	1.560±0.169	0.995
	20	1.023±0.022	1.158±0.120	0.999
	40	1.030±0.018	1.055±0.162	0.999
	60	1.014±0.033	1.195±0.295	1.000
	80	0.995±0.033	1.288±0.277	0.999
	100	0.958±0.050	1.424±0.195	0.999
7	NH	0.919±0.020	6.869±0.320	0.999
	20	0.938±0.021	3.425±0.151	0.995
	40	0.839±0.048	6.367±1.385	0.993
	60	0.880±0.048	5.249±0.663	0.999
	80	0.863±0.011	6.406±0.602	0.999
	100	0.814±0.036	6.699±1.385	0.999
13	NH	0.783±0.107	37.134±2.632	1.000
	20	0.974±0.031	4.905±0.651	0.999
	40	0.854±0.136	15.953±1.106	0.999
	60	0.727±0.109	31.788±2.620	0.998
	80	0.774±0.151	29.856±3.409	0.998
	100	0.856±0.102	13.311±5.376	0.998

Power law parameters: K, consistency coefficient; n, flow behaviour index; means ± standard deviation

CONCLUSIONS

Cooking waters obtained with the simulated continuous cooking procedure were ultrasonically treated for 5 and 20 min and homogenized at pressures ranging from 0 to 100 MPa to evaluate the effectiveness of US and HPH in modifying some physical properties.

During both US and HPH, the energy input is mostly dissipated in cooking water as heat, as a result the temperature of the homogenized cooking water increased with the increasing of ultrasound application time and homogenizing pressure. US application at 80 °C led to water evaporation and thus an increase of solid content when the latter was lower than 2.8%, while no differences were found after high pressure treatment. Ultrasonic treated cooking water increased the turbidity mostly at lower batches, while homogenized cooking water increased the clarity already at the lowest pressure of 20 MPa. Both US and HPH disintegrated the pasta fragments causing noteworthy decrease in apparent viscosity at the milder conditions. These treatments involved cavitation and shear forces that possibly break starch-protein molecule chains. The milder conditions, 5 min of ultrasonic processing time and 20 MPa of high pressure, represented also the most effective in making US and HPH treated cooking waters appear more fresh-like, less viscous on hand and equipment, as well as on cooked pasta surface when handled, and also likely less foaming capable.

The complexity of the equipment, the energy input, the increase of temperature during treatment, the safety requirements, the investment as well as the maintenance costs and safety requirements of each technology are of industrial importance. In conclusion, besides results obtained on laboratory scale, US technology could be the unconventional technology to be implemented in pasta cookers for the treatment of cooking water during the continuous cooking procedure aimed at its optimization.

Part II

Strategies for continuous cooking procedure optimization in pasta cookers

Chapter

5

US technology concept in the professional appliance

INTRODUCTION

Foam formation during continuous cooking in pasta cooker causes cooking water to go into the overflow drain, with consequent water, energy and time consumption. No previous paper seemed to describe foam formation in pasta cookers and more in general in the food service. Based on the TRLs concept, to develop an innovative product, the basic principles have first to be investigated (TRL 1), putting the base for the technology concept formulation (TRL 2) (Mankins, 2009). Here the principles will be discussed.

Liquid foam, commonly referred as foam, is a dispersion of a gas within a liquid that is formed by gas bubbles separated from each other by thin liquid films (Damodaran, 2006). In a liquid foam medium, the volume ratio of gas to liquid is very high, and therefore the bulk density approaches that of the gas.

Stability is one of the most important features of foam because it determines the difficulty of its destruction and the extent of the related problems. In a typical foam structure, bubbles in the lower part are spherical and of smaller size than those at the top. When liquid drains from the upper to the lower layers, the bubble at the top distort to form polyhedral, honeycombed structure of gas bubbles separated by thin liquid walls. As the films at the top become thinner, they are more susceptible to breakage by external stress. However, this process is opposed by the capillary pressure gradient along the height of the foam column, which prevents the liquid from running out. This means that there is a critical height for the foam at which the drain processes and capillary pressure are balanced. Other relevant factors affecting the stability of foams are surface tension, viscosity, pH, molecular surface electrical charge, and temperature (Garret 1993).

In spite of their tendency to collapse, foams can be constituted in such a way that they persist long term or have a long lifetime because of factors such as high viscosity of the liquid and the adsorption of surfactants. Another important characteristic of foam is the use of foamability as a measure of the foaming capacity, which is mainly dependent on the components of the liquid and their relative concentrations (Rodríguez Patino et al., 2008). Based on this, during continuous cooking of pasta in pasta cookers, foam is generated by the agitation, aeration and vaporization of the cooking water by rolling boil.

Several methods are used to prevent the formation of foam (antifoaming) and/or break it once it is formed (defoaming). Antifoamers are foam inhibitors added to the liquid phase to prevent foam formation. Defoamers are foam breakers developed to eliminate the foam (Denkov et al., 2014). Defoaming methods may use chemical or physical effects. Chemical defoaming is based on the use of antifoam agents, which can produce a surface tension gradient acting as a shear force (Pugh, 1996). They are usually surface-active agents formulated to disrupt the surface around the gas bubbles, destabilizing bubble walls so that a bubble can break and release the trapped gas. The number of chemical antifoam agents is very large and includes natural compounds such as sunflower oil, oleic acid, soapslock from plant oil, as well as synthetic compounds such as silicone, polypropylenes, and synthetic fatty acids (Miller, 2008). In general, antifoam agents, are effective for defoaming but may cause serious adverse effects, particularly by contaminating the product. Conventional physical methods for defoaming include thermal, electrical, and mechanical foam breakers. Thermal and electrical methods have hardly been used in practice. Mechanical methods instead have a greater and more widespread use. Mechanical foam breakers collapse the foam bubbles by mechanical shocks produced by centrifugal, compressive, impact or shear forces, suction, or pressure changes. Compared with chemical defoamers, they do not always offer economic advantages, and the design and manufacture of the systems have to be included in the product development steps (Barigou, 2001; Deshpande & Barigou, 2000).

Among the mechanical foam breakers, the use of ultrasonic energy for defoaming has been based on the irradiation of foam by high-intensity ultrasonic waves. It represents a clean means of breaking foams without making contact with them. Therefore, ultrasonic radiation offers a potential alternative to conventional chemical and mechanical techniques. So far, the correlations between ultrasonic parameters (frequency, intensity, and time) and foam parameters (viscosity and density of the liquid, size and distribution of the bubbles, thickness of the foam walls, and compressibility) are still not established (Barigou, 2001). Breaking and destroying foams using ultrasonic energy is assumed to be a combination of different mechanisms. The predominant mechanism is the acoustic streaming, a kind of fluid flow induced by the high-intensity acoustic waves that generates turbulence above the foam interface and may help to destroy the upper layer of bubbles (Boucher & Weiner, 1963). Ultrasonic energy dissipates quickly in the air, the energy transmitted in the defoaming application is large enough to break a thin liquid film in the foam and thus provides a unique way of destroying foam (Patist & Bates, 2008).

The strategy to breaking foam using ultrasonic waves has been explored for several decades mostly on laboratory scale. This could be related to the difficulty in efficiently generating high-intensity ultrasound in air, as well as the lack of knowledge about the mechanism of action of ultrasound on foams. For instance, Dorsey (1959), using a Hartman whistle, applied ultrasonic waves at 26, 29 and 34 kHz for controlling foam formation during a fermentation process. The whistle had no moving parts and was easily sterilized. The higher frequencies showed better results in terms of efficiency and no harmful effects of the ultrasound radiation were observed on culture cells. Sandor and Stein (1993) studied foam destruction via airborne ultrasonic vibrations produced at 20 kHz by using piezoelectrically driven Sonifier probes. Again on

laboratory scale, foam was controlled by an ultrasonic sonicator of 20 kHz with a horn tip with a 12.7 mm cross-sectional diameter for controlling a 15-mm-diameter foam column (Barigou, 2001; Morey, Deshpande, & Barigou, 1999). The probe was used at a distance of 20 mm from the foam, and also in contact with it, showing better results compared to mechanical defoaming tests carried out with low-frequency vibrations of 0-40 Hz. Finally, Dedhia et al. (2004) confirmed the efficiency of using 20 kHz frequency US for defoaming.
On industrial scale, some patents have been registered over the years. The first ultrasonic defoamers were based on the use of aerodynamic acoustic generators, specifically whistle and sirens. Different designs were developed but the efficiency of air jet generators remained very low, together with problems posed by the introduction of an air jet, the noise problems and the high energy consumption (Hay & Shapland, 1970; Sun, 1951). Then, a method and apparatus for removing foam based on the use of an array of sonotrodes was proposed (Matzner, 1980). Foam was produced in the packaging lines of beverages and could be suppressed by applying multiple overlapping ultrasonic wave fields at frequencies of about 20 kHz by means of sonotrodes located above the foam layer. The drawback was related to the very small radiation surface and thus the need to use a large number of units to cover any surface. Other solutions were developed to expand the radiation zone using reflectors concentrating the radiation over the mouth of the bottles or cans (R. P. Singh & Heldman, 2001). Powerful ultrasonic transducers were proved to be effective in destroying the foam when used in the air space directly above a foaming solution (Chemat, Zill-E-Huma, & Khan, 2011; Riera, Gallego-Juárez, & Mason, 2006). From an industrial perspective, almost no solution exists for real situations when foam excess occurs in large reactors or containers. To the best of our knowledge, only a device constituted by stepped-plate transducers has been developed by Pusonics, S.L. (www.pusonics.es) for eliminating foams produced in various practical situations. The units are constituted by one or several piezoelectric power transducers that operate at frequencies of 21 and 25 kHz. It is claimed to be a clean, fast, and efficient system for the control of excess foam produced in fermenting vessels and in other reactors with large dimensions, along with the high-speed canning and bottling lines during filling operations of carbonated beverages (Gallego-Juarez et al., 2010). Up to now, no solutions exist in the food service industry to break foam during cooking and all the mentioned systems imply the use of horns on surfaces.
Along with foam formation, during continuous cooking of pasta in pasta cookers, kitchen operators report cooking water properties change (Chapter 2). Specifically, turbidity increase of cooking water displeased kitchen operators and is associated to viscosity increase that could aid foam stability while affecting the perceived stickiness when handling cooked pasta (Chapter

4). On industrial scale, sonication reactors have been introduced to control viscosity of dairy ingredients (Zisu et al., 2010) but, to the best of our knowledge, any author mentioned the viscosity issue in professional appliances, thus an industrial solution for this is not available up to now.

In the food service, an annoying task that brings together all appliances is cleaning of equipment. Traditional cleaning routines follow a standard protocol, including manual labor, use of water and chemicals by kitchen operators. To decrease the very large volume of water used during cleaning processes, water jets and nozzles have been utilized. The use of nozzles on water jets can considerably reduce the flow rates of water required for cleaning action, but still substantial volumes of water are consumed. In addition, energy consumption is also considerable due to the need for high temperature water. The efficiency of chemicals usually used is then affected by temperature, hardness of water, and other variables that pushes to use over quantities of them. In food industries, to solve these common drawbacks, US-assisted surface cleaning has been introduced and is nowadays one of the most widespread applications of US (Kentish & Feng, 2014; Kieser et al., 2011). The use of US for cleaning has been applied for the removal of adherents from the surface using an aqueous medium as sound transmitter, chemical deposits such as scaling and fouling from equipment surfaces, as well as biological deposits such as biofilms on food surfaces (Otto et al., 2011). In an ultrasonic cleaning process, cavitation and acoustic streaming work together, but the relative contribution of each is a function of frequency. At lower frequencies, cavitation dominates the cleaning process, whereas at higher frequencies, especially when the time between sonic pulses is too short for the formation of cavitation bubbles, acoustic streaming prevails (Awad, 2010). A target frequency of 20–100 kHz and a target-specific power ranging from approximately 0.2 up to 2.0 W/cm^2 was suggested (Otto et al., 2011). Applications of ultrasound include the removal of the fouling of the interior surface and porous membranes of wine barrels (Oulahal-Lagsir et al., 2000) and the cleaning of conveyor belt materials with a thin layer of water using either a protein-rich or a carbohydrate-rich matrix (Axelsson et al., 2013). US have been used not only as a decontamination mean but also as a preventor of biofilm formation on an industrial scale (Lambert et al., 2010).

AIM OF THE STUDY

The aim of the present investigation was to "invent", identify and design the practical application of an ultrasound bath system into the pasta cooker, based on theoretical considerations and findings of Chapter 3. The implementation of ultrasounds in pasta cooker was discussed in the attempt to meet three requirements:

I. Foam breaking;
II. Cooking water viscosity reduction;
III. Well surface cleaning.

To these objectives, continuous cooking was performed to capture images of foam during cooking, cooking water after continuous cooking and adhering starchy layer at the end of cooking. Then, a commercially available transducer was chosen based on power, operating frequency, size, and price. The transducer and the appliance were designed on CATIA software to deliver the layout of the prototype. Finally, drawback considerations were carried out in collaboration with engineers within the GR&D department of Electrolux Professional S.p.A.

MATERIALS AND METHODS

Materials and equipment

Durum wheat spaghetti (2 mm diameter) was purchased from the same specialized supplier to the food service sector (Marr, Italy) as in Chapter 2. The Freestanding Electric Pasta Cooker 700XP (Electrolux Professional S.p.A., Pordenone, Italy) with 1 well of 24.5 L capacity was used for the study. The pressed well was made of 316 AISI stainless steel of 1.5 mm thickness and the infrared heating system was positioned beneath the base of the well. The side edges were right-angled.

Cooking procedure

The pasta cooking process was performed by placing spaghetti strands (2000±1 g) in the steel basket and cooked in 18000 g of boiling tap water with no salt added. Stirring was frequently performed avoiding spaghetti to stick with each other and accumulate on the basket bottom. The pasta was strained above the well for 10 s and discharged. Continuous cooking was performed by adding fresh water in the well up to the initial volume, waiting the temperature to recover the boiling point and starting the new cooking batch. Pasta cooking was performed at 6 kW power rating for 12 batches.

Determinations

Images
Foam, cooking water and adhering starchy layer images during cooking and after cooking were captured using a digital camera (Canon EOS 550D, Tokyo, Japan). Images were saved in the JPEG (5184x3456 pixels) file format.

3D representation
The software CATIA V5 (Dassault Systèmes, Vélizy-Villacoublay, France) was used for shaping the design in 3D on the pasta cooker. The design was carried out in collaboration with mechanical engineers within Electrolux Professional. The ultrasonic transducer considered for the implementation in the pasta cooker is shown in Figure 5.1. The transducer is able to operate at a frequency of 20±1 kHz and a power of 100 W. It has a radiating surface with a radius of 20 mm and an overall height of 30 mm. Its commercial price ranges from 10.0 to 34.95 $.

Figure 5.1. Transducer model used for the pasta cooker ultrasound system.

RESULTS AND DISCUSSION
During continuous cooking in pasta cookers, foam formation, viscosity increase, and the need for a cleaning step represent 3 relevant issues for kitchen operators and the establishment business. In the attempt to solve all these aspects with a single technology and strategy to be implemented in the pasta cooker, US were considered.
For practical reasons, no moving parts should be added, such as Dorsey (1959), and no ultrasonic horn could be used, such as the one used in Chapter 4. In addition, no whistle or sirens represent a feasible solution for noise reasons. An indirect method of sonication using ultrasonic transducers represents the most suitable solution (Kardos & Luche, 2001). The ultrasonic transducer was thought to be bonded to the outside bottom surface or to the outside of the sidewalls, as implemented by other authors (Awad, 2010). In the pasta cooker, the transducer implementation was considered only for the side walls and this was for two reasons: beneath the bottom surface there is the heating system, which consists of an infrared heating system in the model here considered but could be the burners and chimney in gas appliances; then, the implementation has to consider the compatibility with the pace and schedule of the assembly

line in the manufacturing plant. Among the transducers most commonly used for generating ultrasonic vibrations, such as piezoelectric, magnetostrictive, electromagnetic, pneumatic, and other mechanical devices, the piezoelectric transducer assembly was chosen. This is because it is the most widely used configuration in tank-type US treatment devices for their versatility in terms of both size and available frequency range, and price (Mason, 2000). The ceramic materials convert the electrical energy into a mechanical vibration of a particular frequency (Kentish & Feng, 2014). The transducer among all the commercially available ones was chosen based on frequency, power, availability of power supply board, size and price in accordance with engineer specifications and results of Chapter 4. The main parts of the transducer were a resonant mass, connectors, transducers and the radiating cone (Figure 5.2) (Hunter et al., 2008; Kentish & Feng, 2014). The transducer was properly designed on CATIA and the resulting isometric view is shown in Figure 5.3.

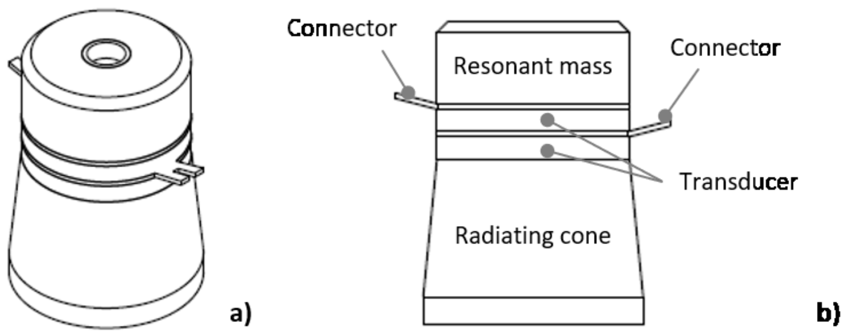


Figure 5.2. Schematic representation of the transducer used for the formulation of the technology concept in the pasta cooker: **a)** isometric view of layout; **b)** front view with the different components (resonant mass, connector, transducer and radiating cone are indicated).

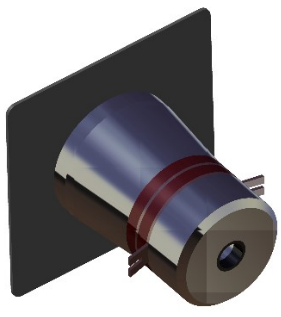


Figure 5.3. Isometric view of the selected transducer as designed on CATIA.

The transducer should be bonded through an adhesive epoxy resin to the external surface of the well wall, connected to the power supply board and inserted in previously cut holes on the insulating material enveloping the well. Considering the height of the transducer and the distance between the appliance external wall and well surface, 49.5 mm, the space between the transducer and the external wall was 19.5 mm, guaranteeing enough space for cables and avoiding the contact with external surfaces.
The radiant units were designed on both the side walls of the tank, opposed, to optimize treatment effectiveness. Due to the nature of waves, acoustic field distribution in the well would be not uniform (Kentish & Feng, 2014). For a correct sizing of the system it was necessary to keep in mind that the transducers couple to the liquid planar compression and decompression waves, therefore with a very limited opening angle. It was therefore necessary that the surface of the radiating units was practically the same as the surface of the frame which must be treated (Kruger, 2011). In summary, transducers were thought to be placed as much close to each other, on side walls and, for space reasons, on the lateral ones.

Foam breaking

The first requirement was the control or avoidance of foam formation during cooking (Figure 5.4).
US represented the most suitable strategy. Four transducers per side were designed above the maximum load mark (Figure 5.5). The dimension of the units allowed to perfectly fit them in the foam volume area of the well, in between the liquid and the overflow drain. Although some mechanisms of defoaming by ultrasounds have been explored, no studies quantifying the separate influence of intensity and treatment time are available (Patist & Bates, 2008). From a practical point of view, this lack of knowledge complicates the optimization of such a technology. Most of ultrasonic defoamers were applied in canning lines or fermenting vessels (Gallego-Juarez et al., 2010), thus two processes were considered: high-speed lines with little exposed surface or very large and static reactors. Foam formation during continuous cooking is a dynamic system with a large foaming surface of 0.111 m^2 on the model here considered. Further, the temperature of cooking is close to the boiling point, which makes the design of such a system more difficult.
During continuous cooking in the optimized pasta cooker, rolling boil provides the energy for the bubbles to form, which are stabilized by the cooking water proteins that at batch 13 were 4.41% (dm) (Chapter 3), while ultrasonic waves could break the resulting foam. US should be applied during the cooking phase, considering the optimal cooking time of the spaghetti used in this research work, this means 13 min 45 s per batch. This means that kitchen

operators do not have to be busy in controlling the appliance during cooking anymore, with reduced water consumption and safety risks.

Figure 5.4. Foam formation during cooking at the 7 batch of continuous cooking.

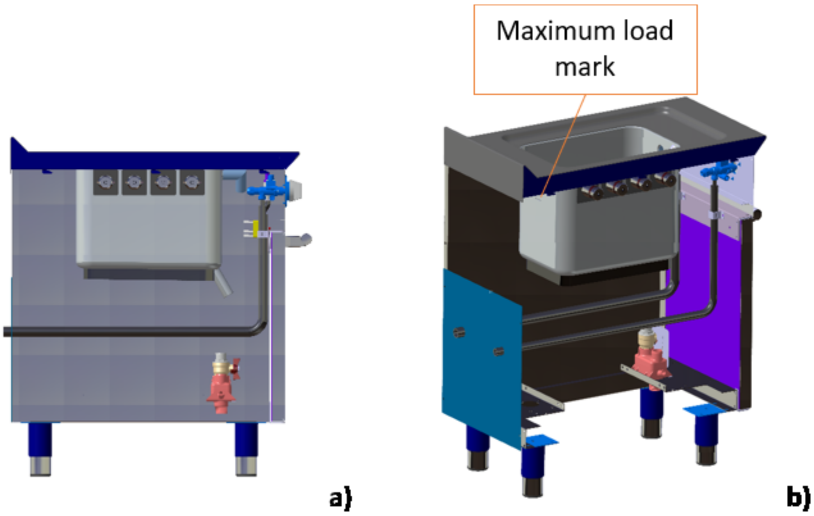


Figure 5.5. CAD representation of pasta cooker with 4 transducers located above the maximum load mark on the left side of the well: **a)** lateral view; **b)** isometric view.

Viscosity reduction

The second requirement was to reduce cooking water properties change as much as possible during the serving hours.

The appearance of cooking water after 12 batch of continuous cooking of spaghetti is shown in Figure 5.6. Of course, only turbidity can be visually appreciated but it is empirically associated to higher viscosity.

The project step was to implement into the pasta cooker four transducers (per side) below the maximum load mark (Figure 5.7). The shear forces induced by cavitation have proved highly effective in reducing the viscosity of cooking water obtained during continuous cooking of spaghetti (Figure 4.4, 4.5 and

4.6). Thus, the transducer could work in between cooking batches in order to reduce the viscosity of cooking water in the attempt to retain fresh-like water properties as long as possible. The effectiveness of ultrasonic treatment was visible already after 5 min of treatment on laboratory scale and this treatment time can be applied in between cooking batches on an industrial scale.
Based on the solution to be treated, the solid content and component type, it takes from 4 to 50 W per liter of liquid (Kruger, 2011). In the pasta cooker, cooking water of pasta contains up to 4.04% of solids (Chapter 4), represented by starch, proteins and minor pasta constituents. Therefore, using 8 transducers working at 100 W each, the effect on cooking water properties on industrial scale should be tested on a prototype.

Figure 5.6. Appearance of cooking water after 12 batch of continuous cooking.

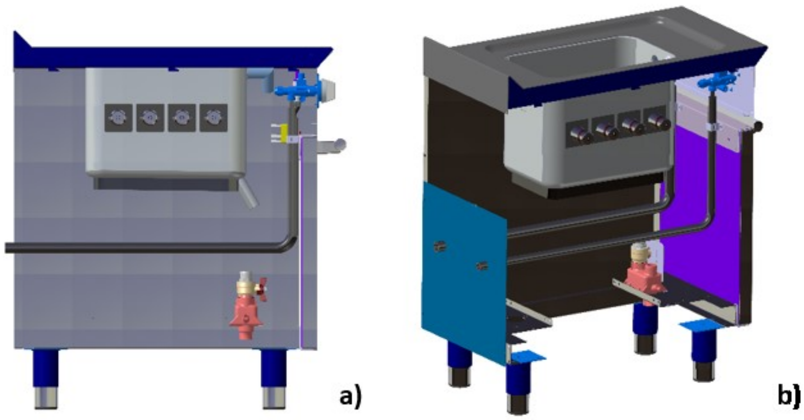


Figure 5.7. CAD representation of pasta cooker with 4 transducers located below the maximum load mark on the left side of the well: **a)** lateral view; **b)** isometric view.

Surface cleaning

The third requirement related to the continuous cooking procedure in pasta cookers was the cleaning step optimization.

Figure 5.8 shows the appearance of the well surface of pasta cooker after continuous cooking of 7 batch. A starchy film sticking to the wall is clearly visible. This is the result of solid leaching into the cooking water of pasta components, which attach to the wall and are not removed by cooking water turbulence in the subsequent batches. In particular, the starchy film was present on the bottom surface and this could be related to the higher temperature and gravity precipitation in between batches. Starch exhibits a marked tendency to adhere to a contact surface. This stickiness was perceived in the palate, teeth, and tongue when the food was being masticated and, such as in this specific case, was also perceived on nonoral surfaces such as fingers and equipment surfaces. In particular, stickiness of material on pasta cooker wall could be attributed to a combined effect of adhesive and cohesive forces, but also viscosity and viscoelasticity as well. Authors reported adhesion of milk constituents on the surface of processing equipment and subsequent fouling in most milk processing plants (Burton, 1968) and adhesion of coagulated milk proteins on surfaces (especially on stainless steel) in continuous cheesemaking machines (Hegg, Castberg, & Lundh, 1985). In the case of pasta cooking, starch and proteins are the most abundant components in leached material and contribute to this stickiness. Cohesion, surface tension, and viscosity all contribute then to the tack (Adhikari et al., 2001).

The strategy here proposed concerns a novel cleaning system in professional appliances, consisting of eight transducers in proximity of the bottom surface where tack mostly occur (Figure 5.9). An ultrasonic treatment of cooking water near the bottom could prevent the precipitation and adhesion of such components to the well surface, in particular, by applying a step of thermosonication in between cooking batches. This means that the ultrasonic treatment could be used in combination with the high cooking water temperature, close to boiling (80-100 °C), to take advantage of the synergism between US waves and temperature. The effectiveness in the removal of adherents is related to the jets induced by cavitational collapse on and near surfaces (Mason, 2000). Therefore, the cleaning of starchy film on pasta cooker walls can be accomplished by the implosion of cavitating bubbles that create shock waves, water jets, and microstreaming.

The power applied (100 W), the available treatment time in between batches (around 14 min, as reported by kitchen operators) and the addition of surfactants in tap water represent 3 factors to be evaluated when testing the efficiency of the proposed solution in a prototype (Mason, 2000).

By theory, the implementation of such a solution leads to the following cleaning suggested procedure:

I. Ultrasound treatment in between cooking batches and as a final cleaning step (Gallo, Ferrara, & Naviglio, 2018);
II. Mechanical cleaning of residues with water by kitchen operators when the well is emptied.

US could represent an environmentally friendly washing method that potentially reduces water, time, labor by operators and detergent consumption introducing an optimized method in the professional appliance.

Figure 5.8. Adhering starchy layer to the well surface of the pasta cooker after continuous cooking of 12 batches.

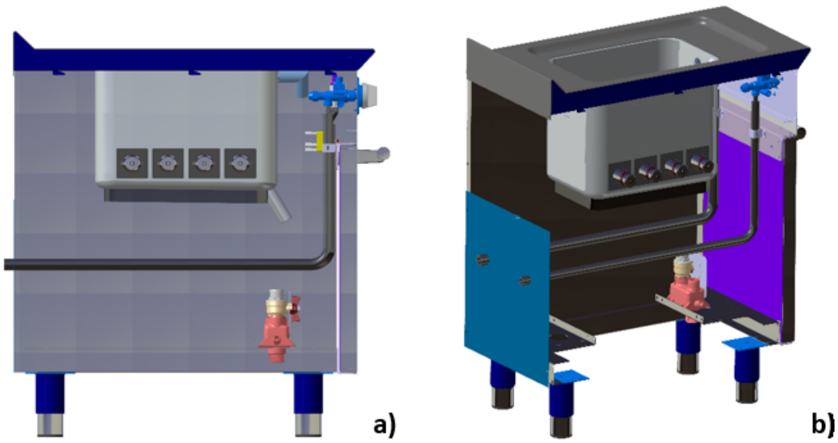


Figure 5.9. CAD representation of pasta cooker with 4 transducers located near the bottom surface on the left side of the well: **a)** lateral view; **b)** isometric view.

The application of US in the cooking water volume (Figure 5.7 and 5.9) could be aimed also at degassing. US forces the small bubbles suspended in the liquid to rise to the surface and release the entrapped gas into the

environment, thus reducing the level of gas dissolved below the liquid level aiding in the defoaming process.
The technology concept comprising all the aforementioned solutions is shown in the appliance in Figure 5.10 and as a front view of the well in Figure 5.11. The upper row was aimed at defoaming, the middle one for cooking water properties retention and the lower for cleaning purposes. The upper was thought to work during the cooking phase (13 min 45 s), while the others in between cooking batches (5 min) and at the end.
The implementation of piezoelectric transducers on side walls of pasta cooker used in professional kitchen was evaluated also in terms of industrial scale manufacturing hurdles, also in light of the TRLs evaluation. One potential drawback of US application is that extended vibration may cause surface erosion because cavitation bubbles exert intense stress on surfaces (Shchukin et al., 2011). Erosion effects increase with ultrasonic intensity up to a threshold of 50 W/cm^2 and are decreasing thereafter. Such an effect has been already observed by Whillock et al. (1997) during the study of US-induced modification of stainless steel. The susceptibility to cavitation erosion should therefore be regarded as a physical property of a particular material and thus *in situ* analysed (Chiu, Cheng, & Man, 2005).
Even though the operating frequency of the proposed transducer was 20 kHz, thus exceeding the threshold of human hearing, the noise could be produced by resonance and subharmonic of the well. To prevent as much as possible noise problems some precautions should be taken: well made in AISI 316 stainless steel, isolating material of at least 100 mm thickness, transducers far from the external walls limiting vibrations, absence of metal parts attached to the well transmitting vibrations (Kruger, 2011). In pasta cooker, all those requirements were fulfilled, but the effect in the prototype should anyway to be tested. Indeed, the noise limit in professional appliances is set at 85 db during exposure time of 8 hours at work (CEI EN 60704-3 2011). For instance, blenders present 82-91 dB (A) of noise at 60 cm of distance (Fischer, Spessert, & Emmerich, 2014).
The power to be supplied to the appliance was at maximum 6 kW for the infrared heating system to work and up to 1.6 kW for the transducers in between cooking batches. Of course, while 6 kW energy was used throughout the whole serving hours, 1.6 kW were only thought to be used 10 min per hour and 800 W for 28 min per hour. Therefore, the cost-benefit analysis as regards the energy demand can give the choice on how much time is needed for the treatment and the requirements have to be prioritized.
The introduction of US must be considered in terms of certifications. In particular in the Italian market, the pasta cooker has to be in accordance with the followings: 2004/108/EC (EMC), 2006/95//EU (LVD), 2011/65/EU (RoHS);

EN 55014-1 (2006), EN 61000-3-2 (2006), EN 61000-3-11 (2000), EN 62233 (2008), EN 60335-1, EN 50581 and finally EN 60335-2-47.
Other factors to be counted in are the acceptability by kitchen operators of an innovative technology in their daily working life in the kitchen and the proper design and cost analysis of the assembly line modification, which have to be evaluated in a close collaboration with plant managers.

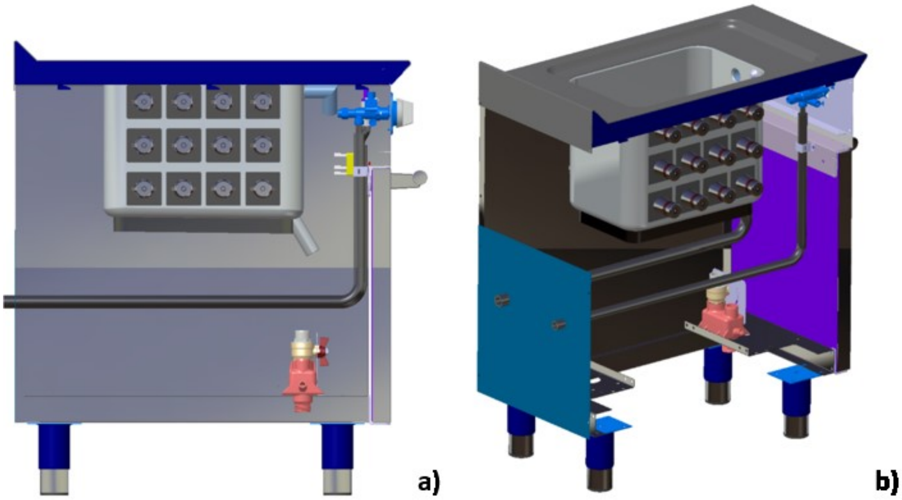


Figure 5.10. CAD representation of pasta cooker with 12 transducers on the left side of the well: **a)** lateral view; **b)** isometric view.

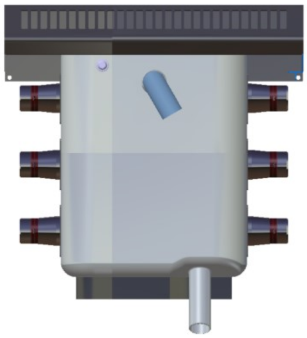


Figure 5.11. Front view of the well with the 3 rows of transducers visible on each side.

CONCLUSIONS
During continuous cooking in pasta cooker, foam formation, viscosity increase, and cleaning represent three aspects that were asked to be optimized by kitchen operators. The strategy here proposed concerned the formulation and design of the layout of an ultrasonic bath system. A proper piezoelectric transducer was selected and up to 24 units were successfully designed on the

well lateral surfaces. The upper 12 units were aimed at physically breaking the foam, the middle ones at reducing cooking water viscosity, and the lower at aiding the cleaning procedure. Cooking water and foam to be sonicated were in the well in direct contact with the wall surface and thus the transducers. This system represented a hybrid system, since there was not a probe to be immersed in the water nor a container or medium in between the US source and the sample.

By using this technology, kitchen operators are relieved from the continuous monitoring of the appliance during cooking and aid in the annoying task when they finish. Within the appliance development, the insight gained in research and design of the technology concept should be translated into an ultrasonic pasta cooker prototype. By validating the proposed implementation for fulfilling all the requirements, an industrial-scale manufacturing process can be developed. The “proof-of-concept” should include the cavitation and thus reliability testing, noise limit production, compliance with national and international standards and certifications, acceptability by kitchen operators and finally engineering costs.

Chapter

6

Pasta simmering by managing the power rating on the professional appliance

INTRODUCTION

Food cooking methods are one of the most essential transformation and have been established based on cooking system prices, consumer nutritional needs and preferences in terms of taste, smell and texture, as well as the culture and ethics. In the food service, such methods have been also selected based on time and energy consumption, taking into account the work flow during the serving hours and possible drawbacks in the specific kitchen environment in terms of efficiency (Bianchi et al., 2019; Pathare & Roskilly, 2016). However, the kitchen operator behaviour may even triple the food cooking energy and water consumption by applying wrong, even if apparently advantageous, procedures. In addition, tradition highly affects food recipes and cooking techniques, and this can hinder the introduction of new or modified methods (Hennchen, 2019; Oliveira et al., 2012).

As concerning the continuous cooking of pasta in professional appliances, high energy and water consumption during the serving hours occur. During cooking, energy is lost from the infrared heating system to the cooking container wall; it is lost by the convection and radiation from the outer surface of the container wall and insulating material; finally, it is lost by the evaporative heat from the free surface of the water. In pasta cookers, there is an additional kind of energy loss, that is, the energy associated with the cooking water volume overflowing into the drain because of foam formation. When wanted, one traditional method for obtaining foam is by using a dispersion technique, which may consist of mechanical shaking or whipping a surfactant solution (Pugh, 1996). In the food service and most of all during pasta cooking in pasta cookers, foam formation during cooking is an unwanted whipping of a surfactant (proteins) solution (cooking water) that represents a huge issue. Such undesirable foaming, if uncontrolled, leads to a number of problems including loss of water, contamination, environment pollution, and reduction in working volume (Deshpande & Barigou, 2000). Up to now, the control of such a problem has been entrusted empirically to kitchen operators. In particular, kitchen operators subjectively manage power rating on the appliance and use empirical means to avoid the loss of water into the overflow drain, and thus energy, as a step of the cooking method. Cooking of pasta is usually carried out in an excess of water at the boiling point (Cocci et al., 2008). As regards the amount of water, the method implies the use of about 10 L of water per each kg of durum wheat semolina dried pasta, while there is no standardized method in AACC Approved Method 66-50 (Barilla, 2019; Peña, Wiesenborn, & Manthey, 2014). Even though some authors reported no influence on pasta cooking quality when the pasta:water ratio is reduced down to 1:3, the standard ratio of 1:10 is still widely used in the kitchens (Cimini, Cibelli, & Moresi, 2019). Even if this means the use of higher volume of water, the cooking efficiency tends to increase with the volume of cooking water or cooking container size. Additionally, the use of a lid on a pot filled with water at the boiling point might cut energy requirements by one-eight by limiting the loss of latent heat during evaporation (Hager & Morawicki, 2013; Newborough & Probert, 2006). The lid can be used on a domestic scale, instead in the food service such a practice would be practically not feasible since kitchen operators always need to visually monitor the appliance, also from far away while working on another task. As regards the temperature, a different cooking method is the passive cooking. Although it may require some additional time to attain the final product, partly cooking a product (first phase) and then allowing it to continue cooking only with the residual heat (second phase) also reduces energy requirements (Kanyama & Bostrom-Carlsson, 2001). This strategy may limit the energy consumption but still it would not solve the foam formation problem in the first phase. Cooking by simmering (85-90 °C) instead of boiling (around 100 °C depending on altitude) has been proposed as a strategy to reduce energy consumption during cooking (Brundrett & Poultney, 1979). This procedure can reduce the evaporation rate and hence also make the kitchen a much more acceptable climate. In the specific case of continuous cooking in pasta cookers, cooking by simmering totally avoids foam formation since the shaking or whipping phenomenon of cooking water is prevented. Finally, safety issues related to rolling boil and foam formation are eluded. Other aspect is the tendency to assume that more vigorous boiling means higher temperatures. The evaporation rate is very rapid under these circumstances and the energy used correspondingly high. Of course, pasta cooking quality must be taken into account, along with the need for more frequent stirring. Pasta stirring during cooking is crucial to yield a homogeneously cooked product without agglomerates and/or partly cooked areas. Data sets about energy use for different cooking methods, appliances and number of portions are incomplete or lacking and no reports can be found about pasta cooking by simmering or at different temperature than boiling during continuous cooking (Kanyama & Bostrom-Carlsson, 2001).

AIM OF THE STUDY

The aim of this research was to study the efficacy of introducing a new cooking procedure for the reduction of water and energy consumption and prevention of foam formation during continuous cooking of spaghetti in pasta cookers.
To this purpose, water boiling tests were carried out to investigate the efficacy of the appliance as a whole in evaporating water and the ability of appliance walls and insulating material in retaining heat. Then, single cooking batches of spaghetti were cooked at 0, 1, 3, and 6 kW power rating in the attempt to find the optimal power rating in terms of foam formation, energy efficiency, water balance, cooking water properties and spaghetti cooking quality. Finally, continuous cooking at 1 and 6 kW power rating was tested for 7 batches with the final aim of identifying the 'best' power rating and cooking procedure to be implemented during continuous cooking in professional kitchens. From a project status evaluations point of view, this represented the Technology Readiness Assessment of the level 4.

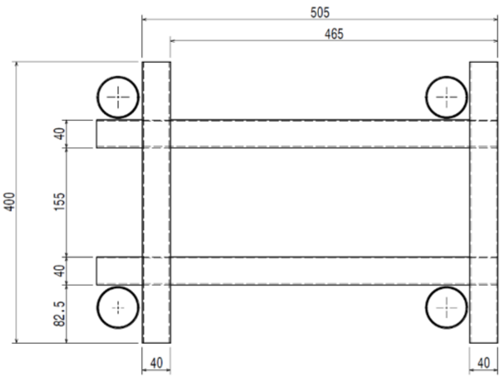
MATERIALS AND METHODS

Equipment

Pasta cooking was carried out in a Freestanding Electric Pasta Cooker 700XP (Electrolux Professional S.p.A., Pordenone, Italy) using a full size basket (Figure 6.1). The pasta cooker had 1 well with a capacity of maximum 24.5 L, a control knob with 4 power levels and a knob regulating a water tap. The pressed well was made of 316 AISI stainless steel of 1.5 mm thickness and the infrared heating system was positioned beneath the base of the well. The side edges were right-angled to allow flush-fitting junction between units and basket was placed on an integrated drip zone. The appliance had four 50 mm legs.

Figure 6.1. Picture of the professional appliance used in the study, **a)** 700XP Pasta Cooker model (Electrolux Professional S.p.A.); **b)** full size basket.

Beams (400x40 mm) were used to support the pasta cooker stably and centrally on a digital scale while preventing the electric cable and drain to touch the scale. Two pipes were attached parallel to the small length of the appliance while the other two were attached lenghtwise to the former (Figure 6.2a). The pasta cooker was thus centrally placed on a digital scale of the series DS 150K1 (Kern & Sohn GmbH, Balingen, Germany) with a maximum load of 150000 g and a reading accuracy of ±1 g. The cooking system is drawn in Figure 6.2b and shown in Figure 6.3, which displays the pasta cooker positioned over the digital scale through the supporting beams.



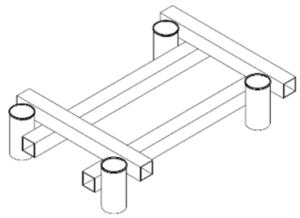


Figure 6.2. Pasta cooker supporting system: **a)** geometric dimensions from above; **b)** isometric view. Dimensions are given in mm.

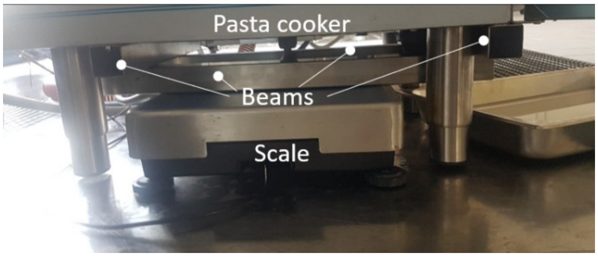


Figure 6.3. Cooking system used with indicated the scale supporting the beam system and the bottom part of the pasta cooker.

Four spacers were screwed at each external side of the basket avoiding the basket to jiggle and so move the probes during cooking.

Throughout all tests, vapour and heat generated during cooking were exhausted outside through a duct with a commercial kitchen hood EP 12/12 (Electrolux Professional, Pederobba, Italy). The kitchen hood was installed at a height of 150 mm from the pasta cooker and worked constantly at the maximum speed during cooking tests. Ambient relative humidity and atmospheric pressure were measured by a thermo hygrometer and barometer 622 (Testo industry corporation, Germany).

During each test, the electric energy consumption was monitored via a Power & Harmonics Analyser Microvip 3 (Elcontrol Energy Net Srl, Marzabotto, Bologna, Italy), characterized by an accuracy of ±1%.

The mass of water evaporated during each test was determined as the difference between the initial and final masses of the pasta cooker filled with water, basket and dry pasta using the same technical balance mentioned above. The mass of water lost into the overflow drain was weighted.
Temperatures were acquired with the following hardware:

- One T thermocouple HF/D-30-TT (Tersid srl, Milano, Italy) placed at 150 mm from the central backside of the appliance was used to acquire the instantaneous ambient air temperatures.
- Five T thermocouples HF/D-30-TT (Tersid srl, Milano, Italy) were used to measure water temperatures and located as near as possible to the internal side of the well. More specifically, four thermocouples were centrally located on each side of the well at 65 mm from the bottom of the well and were named based on the location as follows: “a right” was located on the right internal side of the well; “b front” on the front side; “c left” on the left side; “d back” on the backside. One probe was located 125 mm above the “d back” on the backside only and named “e back”. In particular, the latter was located at the maximum load mark of the well corresponding to 18 L of capacity. Probes had a distance from the well surface of 10±2 mm (Figure 6.4).
- Four T thermocouples PFA-24-TT (Tersid srl, Milano, Italy) were attached to the bottom of the pressed well in correspondence of the maximum nub corners. Probes had a distance from the well surface of 5±1 mm (Figure 6.4).
- Two additional T thermocouples HF/D-30-TT (Tersid srl, Milano, Italy) were used during energy-efficiency evaluation analysis in the basket (50 mm height from the basket bottom and 80 mm from the maximum water level) (Figure 6.4). A wire was put through the basket long sides to centrally support the probes.

All probes were stuck to the surface with Kapton® adhesive tape (DuPont, Wilmington, USA) and had a measurement range of 0-250 °C with an accuracy of ±0.43 °C.

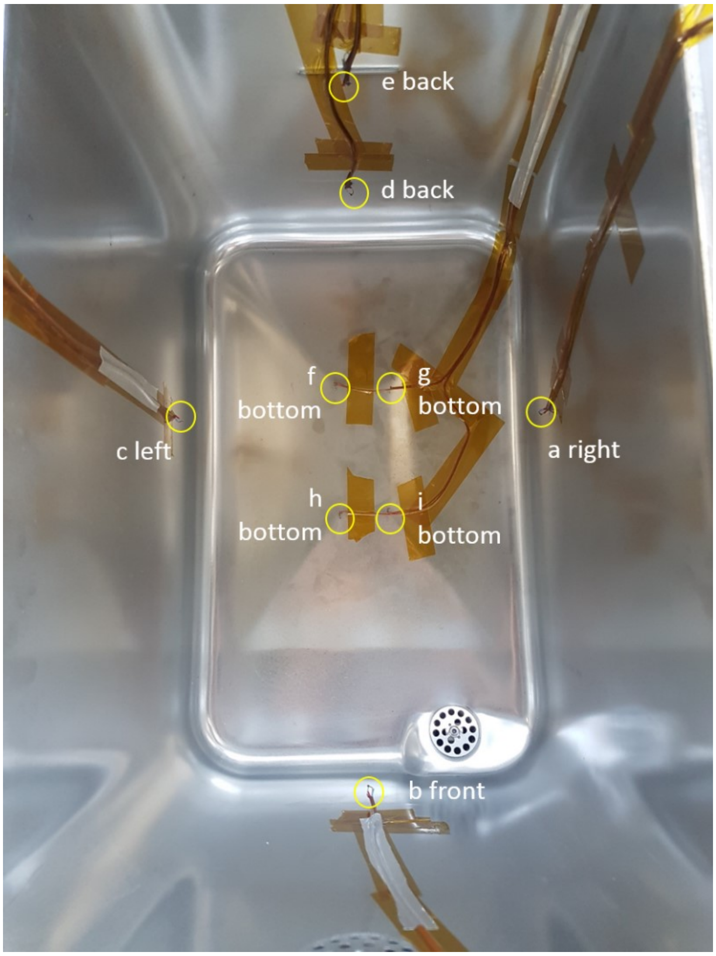


Figure 6.4. Internal surface of pasta cooker well; thermocouples at sides and bottom are indicated.

Figure 6.5. Internal side of basket with the wire supporting the l- and m- basket probes.

Digital scale, thermocouples and Power & Harmonics Analyser were connected to a Data Acquisition System GM90PS (Yokogawa Electric Corporation, Tokyo, Japan). Communication and transfer of logged data was done via a high-speed RS-232 serial port and data was recorded in a computer using LabVIEW® software (National Instruments, Austin, Texas, USA). The data was further analyzed using Microsoft Excel.

Materials

Durum wheat spaghetti (2 mm diameter) was purchased from the same specialized supplier to the food service sector (Marr, Italy) as in Chapter 2. The set time was 660 s supplied by the manufacturer (Rummo, Benevento, Italy).

Water heating and boiling procedure

Pasta cooker was filled with tap water (15±1°C) to the maximum load mark engraved on the well backside and heating until boiling was performed by setting the power rating to the maximum level on the knob. That is, the maximum nominal power rating corresponding to 6 kW power supply, to bring rapidly the cooking water to the boiling point. As the heating process was started, the cooking time, water temperatures, weight of pasta cooker and energy were automatically recorded with a sampling time of 2 s. As water had started to boil, water volume was adjusted to the maximum load and after temperature had reached again the boiling point, the knob was set to four different nominal power ratings (P≈0, 1, 3, 6 kW) and boiling time set to 3600 s. The power rating of 0 kW means that the appliance was switched off during cooking. Energy efficiency during heating and boiling of tap water was evaluated.

Pasta cooking procedure

The pasta cooking process was subdivided into two distinct phases. The first one aimed at heating the cooking water up to its boiling point and followed the heating phase of the previous paragraph, whereas the second one comprised the real pasta cooking phase.

Spaghetti strands (2000±1 g) were placed in the steel basket and cooked in 18000 g of boiling tap water with no salt added. Stirring was frequently performed avoiding spaghetti to stick with each other and accumulate on the basket bottom, especially at 0 kW power. The pasta was strained above the well for 10 s and weighed. Pasta cooking was performed at 0, 1, 3 and 6 kW power rating for 1 batch. Continuous cooking was performed by adding fresh water in the well up to the initial volume, waiting the temperature to recover the boiling point and starting the new cooking batch. Continuous cooking was performed at 1 and 6 kW power rating during the cooking phase for 7 batches. The cooked spaghetti at each batch was analyzed for optimal cooking time, cooking loss, weight increase and water uptake. Cooking water was analyzed for solid content and pH. The cooking performance was analyzed for water temperature drop, recovery time, energy efficiency and wastewater volume.

Determinations

Optimal cooking time

During cooking at the maximum nominal power rating, some pieces of pasta were collected at the set time of 660 s, immersed in cold water (10 °C) and halved to detect the extent of the central white annular portion. The extent of the white central core was taken as reference for the determination of OCTs at the lower power ratings. The OCT was evaluated by taking a sample strand of spaghetti every 30 s and observing the time disappearance of the core of the strand at the reference extent, by squeezing it between two Plexiglas® plates, according to the AACC Approved Method 66-50 (AACC, 2000). The time at which the core disappeared to that extent was taken as the OCT and pictures of squeezed strands were taken.

Water temperature drop and recovery time

The temperature drop (T_{drop}) was determined by subtracting the minimum temperature recorded by the wall thermocouples in the cooking time range of 0-100 s (T_{min}) from the temperature of the water before pasta was added in the well. The time of recovery ($Time_{rec}$) for the water to return to the boiling point after pasta incorporation was measured relative to the moment that the water temperature reached its minimum after pasta incorporation.

Energy efficiency

Appliance heating-energy efficiency was measured from 15 to 90 °C, taking the mean of temperature measured by l-basket and m-basket thermocouples as reference.

The efficiency (η_{heatW}) and energy needed to heat the water (E_{heatW}) have been calculated according to the followings:

$$\eta_{heatW} = \frac{E_{heatW}}{E_{consheat}} \text{ x } 100 \qquad \text{(Eq. 6.1)}$$

$$E_{heatW} = c_{pW}\, m_{W0}[T_W(t) - T_{W0}] \qquad \text{(Eq. 6.2)}$$

The efficiency (η_{evap}) and energy needed to evaporate the water (E_{evap}) have been calculated according to the followings:

$$\eta_{evap} = \frac{E_{evap} + E_{heatW}}{E_{consevap} + E_{consheat}} \text{ x } 100 \qquad \text{(Eq. 6.3)}$$

$$E_{evap} = q_{sW}(t) = W_{lossW} \text{ x } H_v \qquad \text{(Eq. 6.4)}$$

$E_{consevap}$ and $E_{consheat}$ were monitored using the aforementioned Power & Harmonics Analyser.
Figure 6.6 shows the block diagram used to represent the entire input and output energy flow in each pasta cooking cycle. In particular, it visualizes the energy effectively consumed (E_{cons}) in the cooking conditions (heating, evaporation, cooking), the energy theoretically consumed to heat water and cook pasta (E_{th}), as well as all the energy losses to the outside environment, such as the energy dissipated by convection and conduction from appliance (E_{cc}), and the energy used for evaporation (E_{evap}).

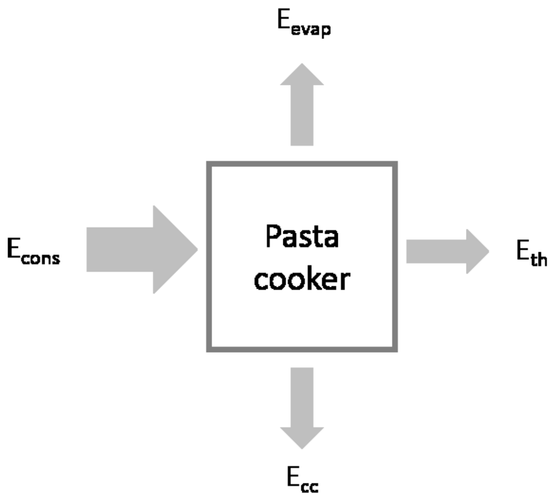


Figure 6.6. Block diagram of the cooking system examined in this work.

The energy efficiency (η_c) of each pasta cooking cycle examined was estimated as the ratio between the instantaneous values of E_{th} and E_{cons}, as follows:

$$\eta_c = \frac{E_{th}}{E_{consOCT}} \text{ x } 100 \quad \text{(Eq. 6.5)}$$

With:

$$E_{th} = q_{sW} + q_{sDP} + q_{gel} \quad \text{(Eq. 6.6)}$$

$$E_{consOCT} = E_{consheat} + E_{consc} \quad \text{(Eq. 6.7)}$$

$$q_{sW} = c_{pW}\, m_W [T_{Wmid} - T_{W0}] \quad \text{(Eq. 6.8)}$$

$$q_{sDP} = c_{pDP}\, m_{DP} [T_W mid - T_{DP0}] \quad \text{(Eq. 6.9)}$$

$$q_{gel} = m_{DP} x_s\, \Delta H_{gel} \quad \text{(Eq. 6.10)}$$

where q_{sW} and q_{sDP} are the energies required to raise the cooking water and dry (uncooked) pasta, respectively, from the initial temperature T_{i0} to the instantaneous water temperature of mid-probe (T_{mid}), this ranging from T_{W0} to the boiling point; whereas q_{gel} is the heat of wheat starch gelatinization, ΔH_{gel} is the enthalpy of starch gelatinization obtained from Ratnayake, Otani, & Jackson (2009). As the dry (uncooked) pasta was the same as the one used in Chapter 4, x_s was obtained from Table 3.1 and data reported on page. E_{consc} was monitored using the aforementioned Power & Harmonics Analyser.

Cooking loss and water solid content

The pasta contained in the basket was poured while collecting cooking water in the well. 150 mL of cooking water from the well was collected in an aluminum vessel immediately after straining for analysis. The cooking water was weighed, placed in an air oven at 105 °C and evaporated until a constant weight was reached. The cooking loss of pasta was expressed as the percentage of the total dry pasta cooked at each cooking batch and the solid content of cooking water as the percentage of the cooking water before drying.

Weight increase and water absorption

To measure the increase in weight of spaghetti during cooking as done in the food service, the weight increase (WI) was determined as the difference between spaghetti weight before and after cooking, according to the following:

$$\text{Weight Increase (\%)} = \frac{\text{CP (g)} - \text{DP (g)}}{\text{DP (g)}} \text{ x } 100 \qquad \text{(Eq. 6.11)}$$

10±1 g of cooked pasta from the basket was collected in an aluminum vessel immediately after straining for analysis. The cooked pasta was weighed (CP_i), placed in an air oven at 105 °C and evaporated until a constant weight was reached (CP_f). The water absorption (WA) of cooked pasta was calculated by relating the weight increase between dry (uncooked) and cooked pasta to the dm content of dry (uncooked) pasta with correction for the cooking loss by Eq. 3.2.

pH

The pH of 500 ml of cooking water collected from the well just after straining and cooling was determined at room temperature with a pH meter HI 9812-5 (Hanna Instruments, Woonsocket, RI, USA). The pH of tap water was measured after boiling for 840 s and cooling.

Water balance in the pasta cooker

The water consumed during cooking (m_{Wcons}) was calculated by:

$$m_{Wcons}(kg) = m_{Wevap}(kg) + m_{WCP}(kg) + m_{Woverflow}\,(kg) \qquad \text{(Eq. 6.12)}$$

With:

$$m_{Wevap}(kg) = m_i(kg) - m_f(kg) - m_{WCP}(kg) - m_{Woverflow}\,(kg) \qquad \text{(Eq. 6.13)}$$

$$m_{WCP}(kg) = \left[100 - \left(\frac{CP_f(g)}{CP_i(g)}x100\right)\right] x\, \frac{CP\,(kg)}{100} \qquad \text{(Eq. 6.14)}$$

and $m_{Woverflow}$ is the wastewater mass lost through the drain because of the overflow and was measured by weighing the discharged water from the drainage pipe.

Statistical analysis

All experiments were performed in triplicate unless otherwise mentioned. Statistical differences in pasta and cooking water were determined by one-way analysis of variance (ANOVA) and Tukey's comparison test ($p < 0.05$). The goodness-of-fit was evaluated based on statistical parameters of fitting (coefficient of determination, R^2 and standard error). The statistical software, R (The R foundation for statistics, v. 3.0.3), was used for the analysis.

Nomenclature

c	=	Cooking phase
cons	=	Consumed
C_{pi}	=	Specific heat of the i-th component
	=	2.256 (kJ g^{-1} K^{-1}) for water
	=	1.840 (kJ g^{-1} K^{-1}) for dry (uncooked) pasta
E_{consi}	=	Energy consumed by the appliance (kJ) during the i-th phase
E_{evap}	=	Latent heat of vaporization added to the water (kJ)
E_{th}	=	Energy theoretically consumed to cook pasta (kJ)
f	=	Final
Heat	=	Heating phase of water
H_v	=	Heat of vaporization
	=	626.66 (W h^{-1}) at 100 °C
m_i	=	Amount of the i-th component used to heat water and cook pasta (g)
q_{si}	=	Sensible heat for the generic i-th component changing its temperature from T_{i0} to T_{Wmid} (kJ)
q_{gel}	=	Heat of starch gelatinization (kJ)
T_{Wmidi}	=	Instantaneous temperature of the cooking water at the generic i-th position (°C)

T_i	=	Initial temperature (°C)
W	=	Water
x_s	=	Mass fraction of starch in dry (uncooked) pasta (g g^{-1})
ΔHgel	=	Gelatinization enthalpy of wheat starch (kJ kg^{-1})
η_c	=	Pasta cooking-energy efficiency (%)
η_{evap}	=	Evaporating-energy efficiency (%)
η_{heat}	=	Heating-energy efficiency (%)

RESULTS AND DISCUSSION

Effect of power rating on heating and boiling of water

During tests, ambient temperature was 25±2 °C, atmospheric pressure was around 1010±2 atm, and relative humidity was 77±3%. Heating of water was carried out at the maximum nominal power rating, a procedure representing the standard heating method in the food service allowing to make the appliance ready-to-use in the shortest time. The boiling point in the well was reached in 1220±180 s as measured by the l- and m-basket-probes. During heating, water temperature difference between the bottom and the wall probes progressively lessened from 8.9±0.5 °C to 0.7±0.5 °C. While the theoretical energy (E_{heatW}) necessary to heat water, as calculated via Eq. 6.2, was 5681±85 kJ, the energy consumed by the appliance ($E_{consheat}$) was 6732±72 kJ. The efficiency to heat water to boiling (η_{heatW}) was thus 84.3%.

Table 6.1 shows the efficiencies to evaporate water (η_{evap}) during the boiling tests performed at different power ratings. During boiling at the maximum nominal power rating, the formation of an intense thrust of water vapor bubbles led to a slight loss of water out of the appliance that was here neglected. During boiling at P≈ 3 kW and P≈6 kW, Eq. 6.3 was used, while during heating and “boiling” at P≈ 1kW and P≈0 kW Eq. 6.1 was used. The evaporation efficiency was slightly negatively affected by lowering the power rating from 6 to 3 kW, decreasing from 89.8 to 88.2%, respectively. The efficiency at 0 and 1 kW was negatively affected by the absence or too low heating energy, respectively.

Adjusting the control knob of the appliance at the different power ratings led to different water temperature profiles after the boiling point was reached (data not shown). When the appliance was supplied by P≈3 kW and ≈6 kW, water temperature remained constant at the boiling point over time leading to efficiencies higher than 88%. Instead, when the knob was set to P≈1 kW, the water temperature started to drop from the boiling point and reached 98 °C in 10 min. Turning off the power rating (P≈0 kW) temperature dropped to 90 °C. This indicates that when ranging between 3 and 6 kW power rating, the water temperature in the well was not highly affected being the absorbed energy during heating and the power during the boiling phase high enough for keeping the boiling point. When decreasing the power lower than 3 kW, the supplied energy did not represent the minimum threshold for water to boil, being dissipated by conduction and convection through the appliance walls and water surface.

Table 6.1. Effect of power rating on the energy consumed by the appliance during evaporation ($E_{consevap}$), the evaporation energy efficiency (η_{evap}) and the final temperature of water (T_f).

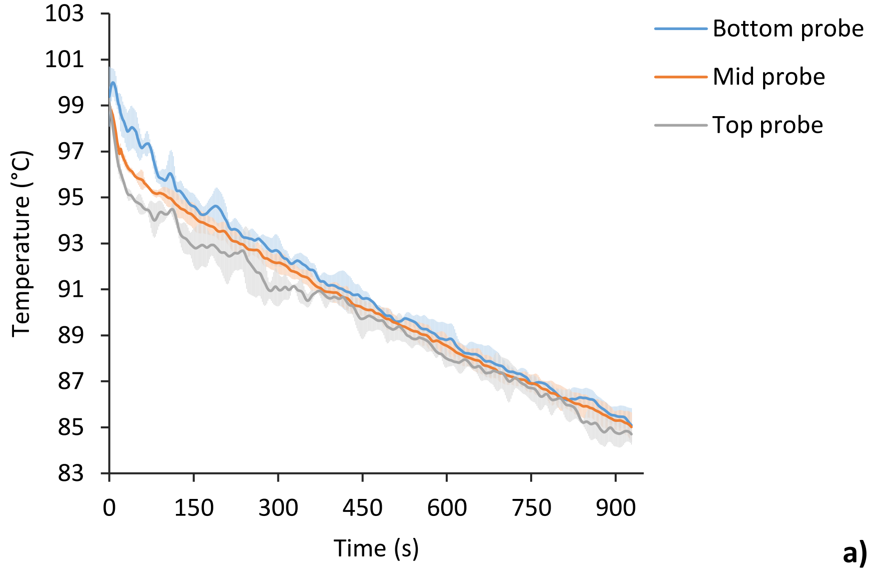
Power rating (kW)	$E_{consevap}$ (kJ)	η_{evap} (%)	T_f (°C)
0	0	73.9±0.4	69.1±0.4
1	3744±36	71.2±0.1	93.5±1.7
3	7836±1195	88.2±0.2	98.4±0.1
6	10140±2093	89.8±0.6	99.2±0.0

Effect of power rating on pasta cooking

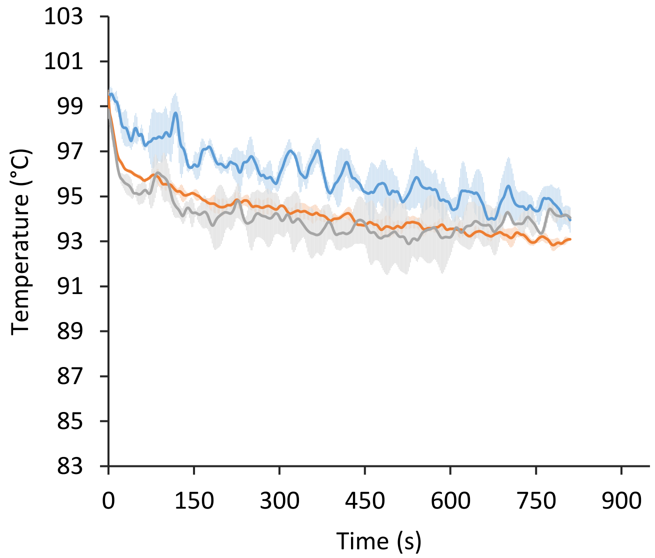
When pasta was added to the boiling water, a sudden decrease in the water temperature was recorded by all the eleven thermocouples in the well (Figure 6.7). This decrease is explained in part by Fourier's law of heat conduction, which states that when a temperature gradient exists within a system, heat energy will flow from the higher temperature to the lower temperature region (Holman, 2002). Therefore, pasta initially at room temperature, rapidly absorbed heat from the boiling water. When the power rating was lower than 3 kW (Figure 6.7a and b), the energy supplied by the infrared heating system under the well bottom surface was not sufficiently high to restore the initial temperature leading to a continuous drop of temperature during cooking. When the power rating was kept higher than 3 kW (Figure 6.7c and d), the pasta cooker restored the energy absorbed by the pasta and resulted in a subsequent increase in water temperature back to the boiling point. The corresponding time required to recover the boiling point of water will be referred as "recovery time" throughout the discussion.

Temperature value variation was due to the convective fluxes. These were related to the mixing action that was frequently carried out during cooking to prevent spaghetti strands to form agglomerates and be non-homogenously cooked. In addition, the collapse of vapor bubbles in correspondence of the thermocouple could lead to sudden changes of the temperature value.

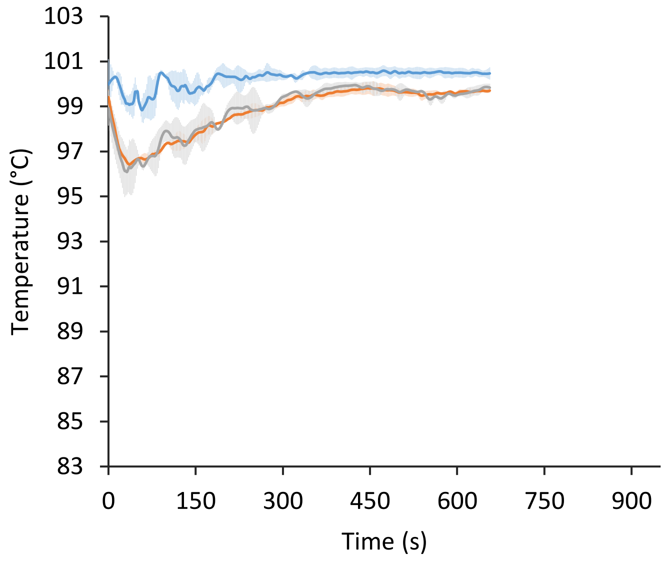
Temperature values were averaged across f-, g-, h-, i-bottom probes for the bottom-probe and a-, b-, c-, d-mid-probes for mid-probe. In all the power ratings here tested, temperatures of the bottom probe were constantly higher than those of the wall because of the heating system position (Figure 6.7). Top probe, located at the initial water level, followed the trend of the wall probes and, therefore, it will not be discussed here after. When pasta cooker knob was kept at 6 kW (Figure 6.7d), the temperature at the bottom was not affected by pasta addition, while at 3 kW (Figure 6.7c) it experienced a slight drop. When power was reduced to 1 kW (Figure 6.7b), the wall temperature was constantly lower than the bottom one. Cooking without heating (Figure 6.7a), i.e. at power off or P≈0 kW, led to differences only during the temperature drop phase, after which heat was homogeneously distributed in the well.



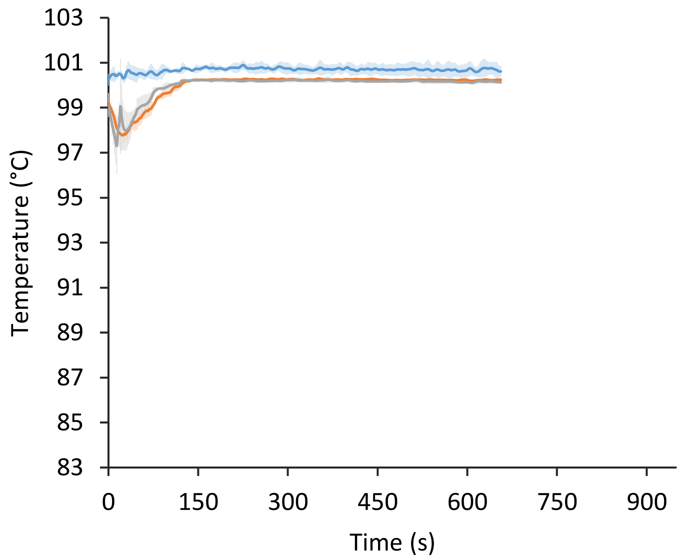
a)



b)



c)



d)

Figure 6.7. Cooking water temperature profiles during the optimal cooking time at: **a)** P≈0 kW, **b)** P≈1 kW; **c)** P≈3 kW; **d)** P≈6 kW. Water temperature is referred to the three different positions in the well. Bottom probe is the mean of f-, g-, h-, i-bottom probes; mid probe is the mean of the a-, b-, c-, d-mid-probes. Lighter lines indicate the standard deviations from the means.

Table 6.2 reports the minimum temperature reached by the thermocouples upon pasta addition (T_{min}), the corresponding drop from the initial temperature to the minimum one (T_{drop}), the time needed to recover the initial temperature ($Time_{rec}$) and the final mid probe temperature at the OCT (T_f). Overall, the wall probe always recorded the lowest minimum temperature than the bottom one. However, during the temperature drop values never fell under 95.1 °C. During cooking, pasta tends to congregate near the bottom of the basket; therefore, it seems reasonable that temperature drop would be greater at the wall beyond which only the insulating material exists rather than at the bottom. This difference increased by increasing the power rating, being 0.7, 1.4, 2.0 and 2.7 °C for P≈0 kW, 1 kW, 3 kW and 6 kW, respectively. When the appliance was switched off, water underwent a greater temperature drop than water heated at higher power ratings. In all cases, the greater the temperature drop, the longer it took for the water to recover its initial boiling temperature (recovery time). The recovery time required for water to recover its boiling point is determined in part by the rate of heat transferred from the infrared heating system to the stainless-steel well bottom, which in turn is determined by the temperature difference between the infrared heating system and water and the resistance to heat transfer. It follows that higher temperatures reached by the well bottom surface through radiation resulted in higher heat transfer to the water, which explains the shorter recovery time when heated at high (3 and 6 kW) rather than low (0 and 1 kW) power ratings. The recovery time at 6 kW was lower than 62 s and increased up to 331 s when power was halved. When spaghetti was cooked at a power rating of 0 and 1 kW, the heat transfer to the cooking water was not high enough to regain the boiling point. This observation indicates that the heat dissipated to the surrounding air was too great relative to the heat supplied by the infrared heating system at that given power rating. Consequently, the temperature at the end of cooking was lower than the boiling point for the lower power ratings (85.05 and 93.52 °C for 0 and 1 kW power rating, respectively).

Table 6.2. Minimum temperature after pasta addition (T_{min}), water temperature drop (T_{drop}), time of recovery ($Time_{rec}$) and final temperature of cooking at OCT (T_f) for cooking at different power ratings. For T_{min}, T_{drop}, $Time_{rec}$ the bottom-probe and mid-probe are reported while for T_f the mean of bottom-probe and mid-probe; with bottom- and mid-probe the mean of f-, g-, h-, i-bottom probes and a-, b-, c-, d-mid-probes, respectively.

Power rating (kW)	T_{min} (°C)		T_{drop} (°C)		$Time_{rec}$ (s)		T_f (°C)
	Bottom-probe	Mid-probe	Bottom-probe	Mid-probe	Bottom-probe	Mid-probe	
0	95.7	95.1	4.6	4.6	∞	∞	85.1
1	96.8	95.4	2.9	3.9	∞	∞	93.5
3	98.4	96.4	2.2	3.0	179	331	100.1
6	100.3	97.6	0.3	2.2	0.01	62	100.4

The effect of power rating on the energy consumed, the energy efficiency for cooking and the water consumed by evaporation and overflow are shown in Table 6.3. The energy consumed for cooking to the OCT was calculated as the sum of the energy to heat water from room temperature to boiling and the one to cook pasta to the OCT by Eq. 6.7. More specifically, since the cooking water was generally heated from 15 to about 99.9 °C, $E_{consheat}$ amounted to about 6732 kJ. This resulted in quite a low cooking energy efficiency of 58.3% at the maximum power that increased to 90.4% when the appliance was switched off for cooking (0 kW). The lower efficiency of the cooking system operating at the maximum power setting undoubtedly derived from the fact that the energy supplied was by far greater than that needed for the pasta cooking process. Throughout the water heating phase (at 6 kW), the energy efficiency (η_{heatW}) was high in the range of 84.3% with the overall mass of water evaporated of 0.2±0.1 kg. During cooking at 0 and 1 kW power, the mass of water evaporated was 0.4 kg, while at 6 kW was 1.3 kg. The intense evaporation of water represents a waste of cooking water and energy that should be avoided. This founding also corroborated our assumption that a good practice is performing the cooking phase at the minimum power, i.e. 1 kW. At this power, the energy efficiency was high enough, with low mass of evaporated water and no foam formation, and thus no overflow during cooking. This power rating also allowed to keep water temperature in the well over 93.52 °C (Table 6.2) reasonably guaranteeing cooking of pasta to occur properly.

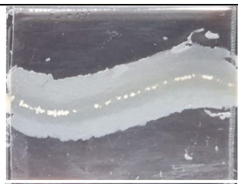
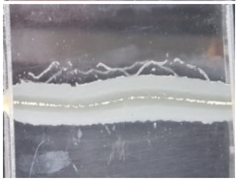
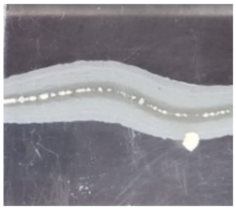
Table 6.3. Effect of power rating on the energy consumed by the appliance during the cooking phase to the OCT ($E_{consOCT}$), the pasta cooking energy efficiency (η_c) and water consumed by evaporation (m_{Wevap}) and overflow ($m_{Woverflow}$).

Power rating (kW)	$E_{consOCT}$ (kJ)	η_c (%)	m_{Wevap} (kg)	$m_{Woverflow}$ (kg)
0	7404±145.5	90.4±1.6	0.4±0.1	0
1	8268±145.5	80.9±1.6	0.4±0.1	0
3	9499±87.1	70.1±0.6	0.6±0.1	0
6	11460±145.5	58.3±0.8	1.3±0.4	2.1±0.3

Cooking starts on the surface of the spaghetti strand and progresses toward the core of the strand in a radial direction (Fasano, Primicerio, & Tesi, 2011; Del Nobile et al., 2003), and it involves the gelatinization of starch and the (further) polymerization of the protein present in the gluten matrix (Lambrecht et al., 2017). Thus, cooking requires that pasta is heated above the gelatinization and protein polymerization temperature and that the temperature is held as the water penetrates into the strand. The temperature for starch gelatinization and protein polymerization to occur is usually over 50 and 90 °C, respectively (Bruneel et al., 2016; Sissons et al., 2012). It follows that pasta cooking starts before the boiling point has been reached. When pasta was cooked at a power rating of 0 and 1 kW, the water never boiled again (Table 6.2). However, to reach the same cooking extent, pasta required a significantly longer cooking time than when cooked at higher power ratings. In Table 6.4 the OCTs and the corresponding images of spaghetti central white core are reported. The set time provided by the manufacturer was taken as the OCT at P≈6 kW. A spaghetti strand as pressed between two Plexiglas plates exhibited three concentric zones (Sicignano et al., 2015). The external area appeared to be swollen, the middle one denser and the inner one almost compact, probably due to lower levels of hydration and degree of starch gelatinization at this time. The OCT of 660 s was thus considered the time needed to get the desired "al dente" texture and degree of cooking fitting with food service requirements, lower than the 825 s as determined in Chapter 2.

While at P≈3 kW the OCT did not increase, lowering the power supply to P≈1 and 0 kW led to an OCT of 810 and 930 s, respectively. This result can be related to the temperature distribution in the well during cooking (Figure 6.7). When temperature slightly dropped but recovered the boiling point, pasta cooking occurred at similar rates. Instead, when temperature continued to drop, cooking rate in pasta slowed down. In addition, comparing the squeezed spaghetti cooked at P≈0 kW with the ones at P≈6 kW, the former appeared to have a wider middle region with lower density and an irregular external area. This indicates that the higher cooking time allowed to reach the same cooking extent in the central core, while being too long for the heat and water exposure at the external and middle spaghetti areas.

Table 6.4. Effect of power rating on optimal cooking time (OCT) and the corresponding appearance of spaghetti strand.

Power rating (kW)	OCT (s)	Images
0	930[a]	
1	810[b]	
3	660[c]	
6	660[c]	

[a]Values followed by the same letter in the same column are not significantly different (p<0.05)

Greater cooking losses were found when pasta was cooked at 6 kW power rating than for any other configuration (Table 6.5). Cooking losses of pasta decreased when pasta was cooked at 0 and 1 kW, and further decreased when the power rating was 3 kW. At 6 kW a strong rolling boil was obtained in the cooking well, which enhanced the movement of the strands, promoting surface disintegration and cooking loss. In addition, pasta was subjected to harsher conditions, i.e. a foam layer was formed after 240±60 s of cooking, which could result in larger amounts of starch granule disruption and higher cooking losses. Instead, intermediate cooking losses at 0 and 1 kW were associated to longer cooking time for starch gelatinization at the core of the strand that concurrently led to higher hydration of external areas and thus components leaching (Sobota & Zarzycki, 2013; Zweifel et al., 2003). Cooking loss at 3 kW was slightly lower.

No differences in weight increase were detected between the samples (Table 6.5). This is valid also for water absorption, whose values were not significantly different among the different power rating used.

Table 6.6 shows the solid content of the cooking water resulting from pasta cooked at 0, 1, 3 and 6 kW power rating. The maximum power led to the highest solid concentration of 0.87% while no differences were detected in all the other cases ranging from 0.62 to 0.65% for power rating 3 and 0 kW, respectively. The higher solid content confirmed that spaghetti strands were exposed to harsher mechanical and thermal stresses during cooking by rolling boil. The higher solid content was accompanied by a lower pH in cooking water, which confirmed the observations of Chapter 3 (Figure 3.3).

Table 6.5. Effect of power rating on cooking loss (CL), weight increase (WI) and water absorption (WA) of cooked pasta.

Power rating (kW)	CL (%)	WI (%)	WA ($g\ g^{-1}$ dm)
0	3.5±0.2[ab]	142.4±1.7[a]	1.6±0.1[a]
1	3.4±0.2[ab]	142.7±4.6[a]	1.6±0.1[a]
3	3.2±0.3[b]	139.2±2.4[a]	1.6±0.1[a]
6	4.0±0.2[a]	142.0±0.3[a]	1.6±0.1[a]

[a]Values followed by the same letter in the same column are not significantly different ($p<0.05$)

Table 6.6. Effect of power rating on solid content (SC) and pH of cooking water.

Power rating (kW)	SC (%)	pH
0	0.7±0.0[b]	7.2±0.2[bc]
1	0.6±0.1[b]	7.4±0.1[b]
3	0.6±0.1[b]	7.8±0.1[a]
6	0.9±0.1[a]	6.8±0.1[c]

[a]Values followed by the same letter in the same column are not significantly different ($p<0.05$)

Cooking of 1 batch of pasta at different power ratings led to different results in terms of energy efficiency, overflow, water use, cooking water properties and cooking loss of pasta. Even though cooking at 1 kW power rating increased the cooking time by 150 s compared to the standard 6 kW power rating, the results on water temperature profiles, energy efficiency and water balance suggested to use the former during the continuous cooking procedure in the food service.

Effect of power rating on continuous cooking of pasta

Continuous cooking of pasta in the pasta cooker was performed for 7 batches at the minimum, i.e. 1 kW, and maximum power rating, i.e. 6 kW. In between batches, cooking water was heated up at 6 kW, while upon pasta loading it was properly adjusted for the cooking phase.

Figure 6.8 shows the temperature profiles of cooking water in the different position in the well (bottom, mid-wall and top) during the continuous cooking procedure. Cooking at 1 kW (Figure 6.8a) led to a drop of all the temperature curves right after pasta loading. Temperature slightly increased before starting to drop again. At the well bottom, water temperature was constantly higher than that at the mid and top of the well for all the batches, following the same trend as in Figure 6.8b. In between batches, temperature dropped down under 61.1, 81.7 and 70.4 °C for top, mid and bottom probes, respectively. During cooking at 6 kW (Figure 6.8b) instead led to a smaller drop of temperature in the well and the fast recovery of temperature to boiling point for all the batches, as seen for a single batch in Figure 6.8d. The drop of temperature in between batches went under 36.3, 45.9 and 44.6 °C for top, mid and bottom probes, respectively. This difference of minimum temperatures in between batches during cooking at 6 kW instead of 1 kW was related to foam formation and overflow. Foam layer (Figure 6.9) started to form after 240 s of cooking at each cooking batch leading to the water level to rise and the cooking water to go into the overflow drain. This led to a huge volume of water to be lost, which had consequently to be restored at the end of cooking before the following pasta loading. Addition of more fresh water caused a greater drop of temperature in the well and therefore a longer time for the boiling point to be reached.

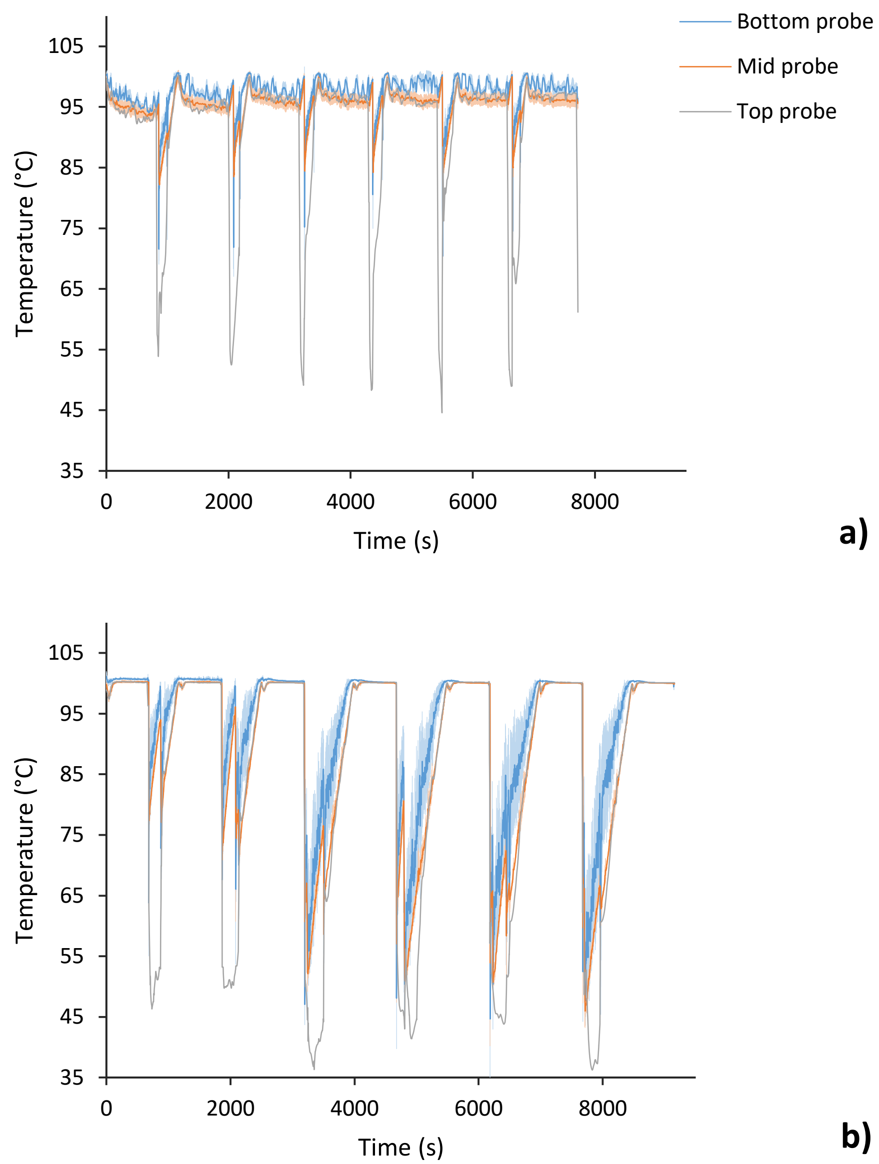


Figure 6.8. Cooking water temperature profiles during the continuous cooking of seven pasta batches at: **a)** P≈1 kW, **b)** P≈6 kW. Water temperature are reported on the three different position in the well. Bottom probe is the mean of f-, g-, h-, i-bottom probes; mid probe is the mean of the a-, b-, c-, d-mid-probes.

The effect of batch number on the energy consumed for cooking when continuous cooking was performed at 1 and 6 kW is shown in Figure 6.10. The energy consumed for cooking to the OCT at the selected batch was calculated as the sum of the energy to heat water from the end of the previous batch to pasta loading and the one to cook pasta to the OCT. More specifically, for the

first batch, $E_{consheat}$ amounted to about 6732 kJ, being the freshwater temperature in the range of 15±1°C and the power rating set at maximum. The consumed energy dropped from the first to the second batch while slightly increased for the followings when power was kept constantly at 6 kW and decreased when it was switched to 1 kW. The drop at the batch 2 is explained by the higher energy needed to heat the initial water volume up to boiling. The increase in the use of energy during continuous cooking at 6 kW is due to the overflow occurring during cooking, which emptied the well. This supports what reported by Hager and Morawicki (2013).
The energy efficiency of the cooking system at each cooking batch is shown in Figure 6.11. The lower efficiency of the cooking system operating at the maximum power setting throughout the continuous cooking confirmed what was previously seen and discussed for a single batch (Table 6.3). Interestingly, η_c decreased from 57.8 to 28.3% from batch 1 to 2, while slightly increased up to 43% for batch 7, at 6 kW. At 1 kW, η_c decreased from 80.7 to 50.6% from batch 1 to 2, while it was 55% for batch 7. Based on these results, it is clear that performing the cooking phase at the minimum power, i.e. 1 kW, leads to higher energy efficiency, no overflow, and thus no waste of water at each cooking batch here tested.

Figure 6.9. Picture of foam layer causing the water to go into the overflow drain at power rating of 6 kW.

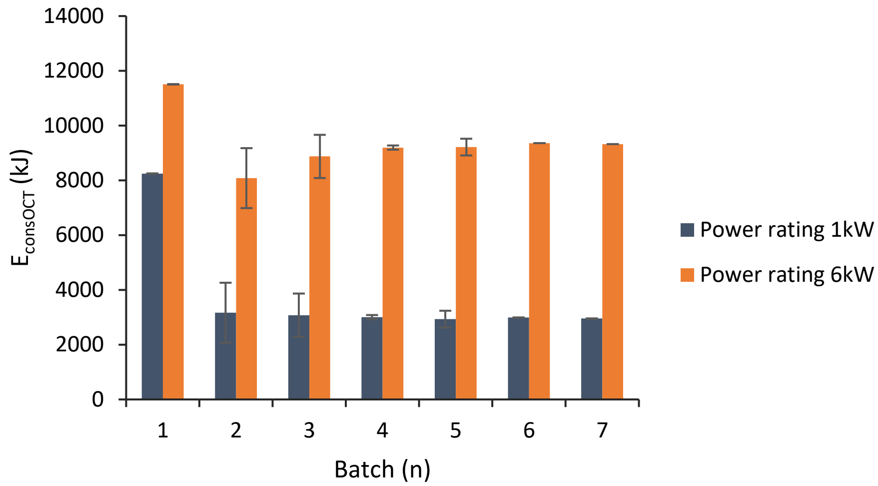


Figure 6.10. Effect of batch number on the energy consumed by the appliance to the OCT ($E_{consOCT}$) at different power rating.

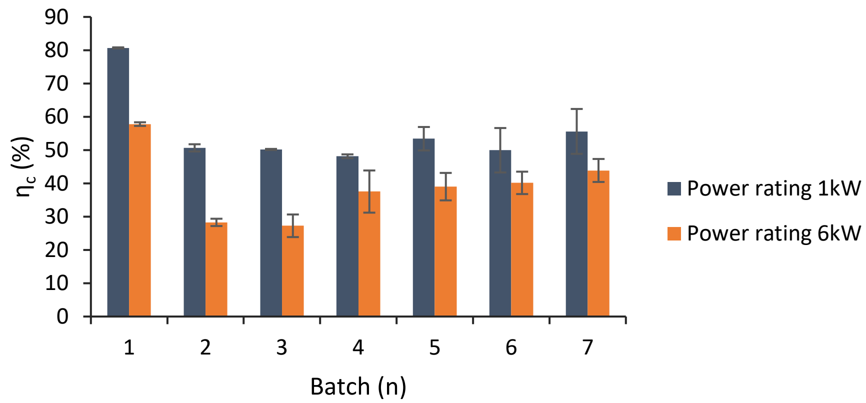


Figure 6.11. Effect of batch number the pasta cooking energy efficiency (η_c) at different power rating.

At the end of the continuous cooking procedure, the total energy consumed by performing the cooking phase at 1 kW was 26376 kJ, which was much less than the 65562 kJ consumed when the maximum power was used (Table 6.7). Overflow led to a waste of 52.26 kg of water into the overflow drain, which needed to be restored and heated up. Overflow led also to an increase of total time for the continuous cooking procedure of 1508 s, even though the OCT at 1 kW power was longer of 150 s. These results further confirmed the great saving of time, energy and water that can be achieved by modifying the continuous cooking procedure from rolling boil to simmering, thus from cooking with 6 kW (standard use) to 1 kW power rating (proposed strategy). By lowering the power rating, for the kitchen operators seemed disadvantageous for the drop of temperature and longer cooking times, accompanied by a change in product quality. Instead, for the first time the advantages are here clearly shown.

Table 6.7. Consumed energy (E_{cons}), time, mass of water related to overflow ($m_{Woverflow}$) at the end of the continuous cooking procedure for 7 batches at 1 and 6 kW power rating.

Power rating (kW)	E_{cons} (kJ)	Time (s)	$m_{Woverflow}$ (kg)
1	26376	7831	0
6	65562	9339	52.3±3.5

The consequence of overflow is the addition of a greater amount of water in between batches that decreases the solid concentration in the cooking water keeping its properties closer to the first batch. This effect is visible in Figure 6.12. Solid content in cooking water progressively increased when pasta was cooked at the minimum power while it was constantly lower than 1.06% for all the batches when cooking was performed at the maximum power. This lower solid content, though, did not prevent the foam layer to form. Foam formation indeed occur thanks to the proteins leached out of the pasta during cooking that diffuse to and adsorb at the air-water interface, thereby lowering surface tension (Fameau & Salonen, 2014). Rolling boil provides the energy input to form the air cells that are then stabilized by pasta proteins. Apparently, the proteins present in the cooking water up to the batch 7 were able to stabilize the vapour bubbles. When pasta was cooked by simmering, there was no energy for the gas cells to form and growth in size and number, and thus proteins did not find interfaces to be stabilized. This result suggests that the waste of water into the overflow drain does not have the advantage of diluting the remaining water in the well and so preventing the foam formation in the subsequent batches, hypothesis that was supported by kitchen operators instead.

The similar solid content of different batches at 6 kW power rating led to similar pH values ranging from 8.3 to 8.6 (Figure 6.13). On the contrary, the increase in solid content of cooking water when 1 kW was supplied led to a decrease of pH from 7.9 to 6.7, thus from alkalinity to acidity.

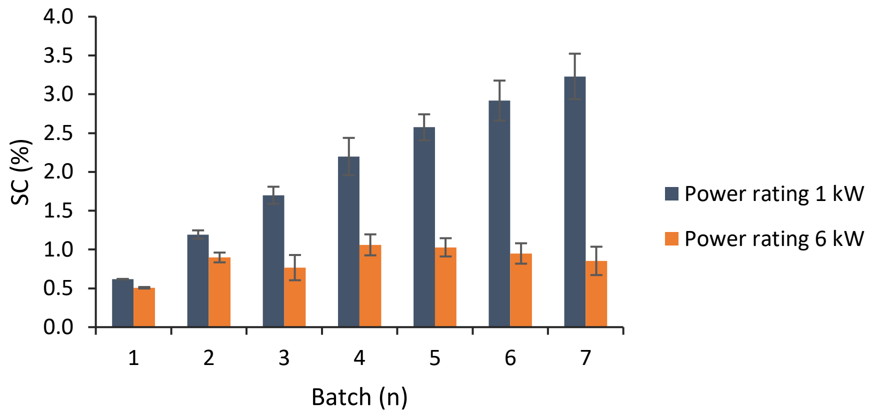


Figure 6.12. Effect of batch number on solid content (SC) in cooking water of pasta cooked at different power rating.

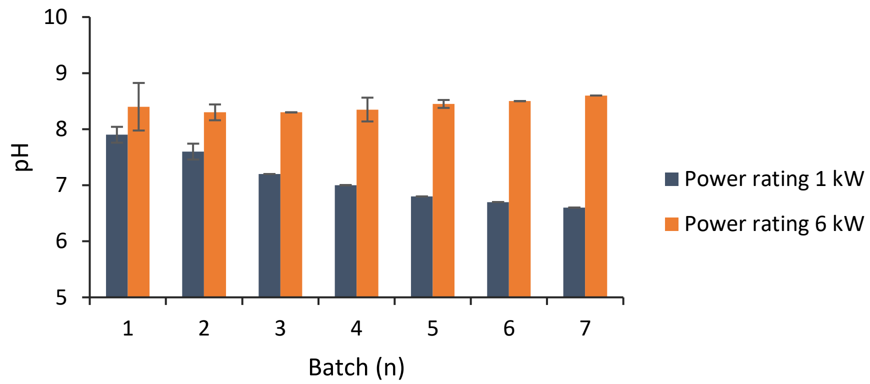


Figure 6.13. Effect of batch number on pH in cooking water of pasta cooked at different power rating.

Continuous cooking did not affect the weight increase and water absorption either at 1 or at 6 kW (data not shown). However, when considering the mean among the 7 batches, cooking at the minimum power led to a higher water absorption but similar weight increase (Table 6.8). This could be related to the higher cooking time leading to higher water hydration, particularly by the strand external region. Finally, greater cooking loss was found for pasta cooked by continuous cooking at 6 kW power rating, confirming the negative effect of rolling boil compared to simmering on pasta cooking quality.

Continuous cooking led to a decrease of cooking loss when pasta was cooked both at 1 and 6 kW power rating (Figure 6.14).

Table 6.8. Effect of power rating on the water absorption (WA) and weight increase (WI) of cooked pasta. Values are the mean ± standard deviation of 7 batches.

Power rating (kW)	WA ($g\ g^{-1}$ dm)	WI (%)
1	142 ± 1^{a}	1.6 ± 0.1^{a}
6	137 ± 3^{b}	1.6 ± 0.1^{a}

[a]Values followed by the same letter in the same column are not significantly different ($p<0.05$)

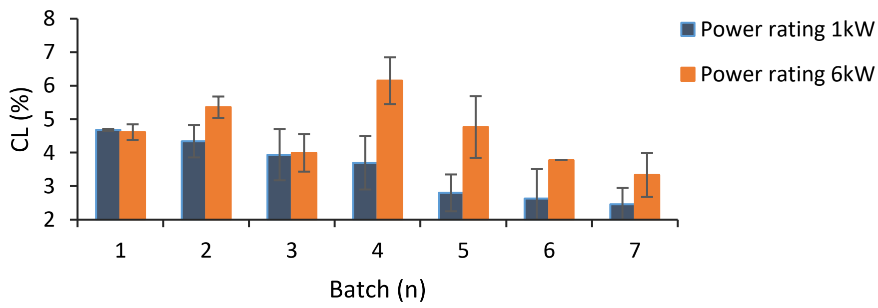


Figure 6.14. The effect of batch number on cooking loss (CL) at different power rating.

CONCLUSIONS

The power rating was shown to influence significantly the cooking time, energy efficiency, water use, cooking water properties and cooking loss of pasta by affecting the water temperature, foam formation and heat transfer kinetics during the cooking process. The efficiency of the electric pasta cooker to heat and boil only water increased from 73.9 to 89.8% when managing the power rating from 0 to 6 kW. Cooking for a single batch was performed at 0, 1, 3, and 6 kW power rating. Decreasing the power supply from 6 to 1 kW, the OCT increased by 18.5% because of the temperature drop in cooking water down to 93.5°C. However, cooking by simmering and not rolling boil by managing the power rating allowed to avoid foam formation completely and therefore reduce energy and water consumption. This led to an increase in the energy efficiency up to 80.9% and a decrease of water consumption down to 0.4 kg. Pasta cooking quality was affected in the cooking loss while solid content of cooking water increased, and pH decreased when applying higher power ratings. Cooking at 1 kW power rating appeared to be the best compromise between OCT and all the other factors. Therefore, continuous cooking was investigated at this power rating compared to the standard procedure. By using 1 kW power rating during continuous cooking, the drop of temperature in between batches was lower and this was related to the absence of foam formation that prevented water to go into the overflow drain. Overflow water counted 0 kg, while it was 52.3 kg at 6 kW. Following, energy efficiency was constantly higher when cooking by simmering compared to rolling boil, leading to a consumed energy for the whole continuous cooking procedure of 26376 kJ for cooking at 1 kW compared to the 65562 kJ at 6 kW. The lower solid content and higher pH of cooking water for samples at 6 kW power did not prevent foam formation and greater cooking loss. These results support that cooking pasta by simmering instead of rolling boil is possible and actually it is even advantageous.

In conclusion, the acquired results provide fundamental information to select the most appropriate procedure to prevent foam formation. By using this information, such a cooking practice might be easily converted in a built-in procedure to manage automatically the cooking method so as to cut significantly time, water and energy consumption while retaining cooked pasta technological properties. Of course, this strategy has to be proposed and accepted by kitchen operators and chefs, who can now apply a food science-based approach to solve the issues related to this traditional kitchen procedure.

Chapter

7

General discussion

INTRODUCTION

In the food service sector, both the kitchen operator and the consumer in the establishment drive the professional appliance choice in terms of model, category and brand. Organization, efficiency, time management, productivity, personalization, and safety are just examples for needs of kitchen operators. Food quality, service environment and service performance are the three main criteria used by consumers to evaluate the establishment. Professional appliances play a critical role in almost all of them and result from a collaboration between engineers and kitchen operators. So far indeed, in most cases, the research and development in the manufacturing of such appliances has been entrusted to engineers having a technical background. The performance of the food process is validated on a culinary base by kitchen operators, instead. This dialogue lacks an integrated approach between kitchen operators and engineers, and scientific knowledge of food and food processing. Food scientists are asked to fill this gap, and this requires a new experimental approach and basic scientific research based on a professional knowledge of industrial procedures.

In this PhD thesis, the continuous cooking of pasta in pasta cookers was chosen as study case. The continuous cooking procedure and the use of US and HPH on cooking water (I part), and the formulation of the technology concept of US bath system (TRL 2) and power rating management (TRL 3) as optimization strategies (II part) were investigated. In particular, the part I describes the effect of the simulated continuous cooking procedure on technological and textural properties as well as leaching behaviour of pasta, and rheological and physico-chemical properties of cooking water (with and without pasta fragments). Moreover, the effect of US and HPH on cooking water physical properties was investigated on laboratory scale. The part II was addressed to "invent", identify and design the practical application of US bath system into pasta cookers aimed at breaking the foam, retaining cooking water physical properties and aiding the appliance cleaning procedure for kitchen operators. Furthermore, cooking by simmering was introduced by managing the power rating on appliance knob for reducing energy, water and time consumption by preventing foam formation.

MAIN FINDINGS

In Chapter 2, the continuous cooking procedure was simulated on laboratory scale. The results acquired showed that the continuous cooking procedure of 12 batches led to an increase in solid content of cooking water that resulted in an increase in shear-thinning behaviour and consistency index. Pasta cooking loss as well as the swelling index decreased, while surprisingly, continuously cooked pasta got firmer but not stickier.

In Chapter 3, the results evidenced that the continuous cooking procedure of 13 batches resulted in a lower mobility of components inside the pasta matrix, which led to a retention of proteins, particularly albumins and globulins, and starch in cooked pasta. Increasing solid content and dropping pH were identified as relevant factors for the cooking water. Additionally, continuous cooking increased the foaming stability of cooking water while the separation of pasta fragments did not play a role.

In Chapter 4, both US and HPH energy inputs were dissipated as heat in cooking water; US applied at 80 °C led to an increase of solid content, while no differences were found after HPH treatments. Only the latter was effective in reducing cooking water turbidity (already at 20 MPa) while both technologies at milder conditions (5 min US and 20 MPa HPH) were responsible for apparent viscosity reduction.

In Chapter 5, an US bath system was "invented", identified and designed into the pasta cooker. A proper piezoelectric transducer was reported and up to 24 units were successfully designed on the well lateral surfaces with a 3D layout aimed at physically breaking the foam during cooking, reducing cooking water viscosity in between batches and optimizing the cleaning procedure at the end of the serving hours.

In Chapter 6, the results showed that the management of power rating during continuous cooking represents an effective strategy, named simmering, for reducing total cooking time, energy and water consumption, by avoiding foam formation and overflow into the appliance drain. Cooking by simmering was performed at 1 kW power rating and resulted in higher solid content and lower pH in cooking water but lower cooking loss when compared to the standard rolling boil performed using 6 kW power supply.

IMPLICATIONS FOR THE PROFESSIONAL APPLIANCES INDUSTRY

Continuous cooking procedure of pasta in pasta cookers

The outcomes of this research highlighted that the continuous cooking procedure carried out in professional kitchens causes modifications of technological properties of pasta, physical and chemical properties of cooking water, and water and energy wastes. However, it is evident that the type of tap water used (different pH and mineral content) (Sozer & Kaya, 2008) and the procedure carried out (pasta:water ratio, different power rating, specific appliance) have to be properly selected to describe an operating protocol for future research. Indeed, already Peña et al. (2014) highlighted the absence of testing parameters in the international approved method (AACC, 2000), which along with the absent information about pasta continuous cooking (Korzeniowska et al., 2005) in the food service, made the comparison of the acquired results more difficult.

The simulation of continuous cooking procedure on laboratory scale works in the direction of improving the knowledge on pasta cooking by applying an analytical approach to an industrial context. Moreover, physico-chemical, textural and rheological analysis that are usually employed to investigate hypothesis on laboratory, permit now to evaluate issues based on consumer insights and kitchen operator requests (Salazar et al., 2012). From an educational perspective, the introduction of a food science-based method permits to approach important issues in appliance development: design for preventing misuse practices, structured procedures for testing and a common language to speed up strategies' implementation in collaboration with engineers and kitchen operators.
Along with the simulation of continuous cooking procedure and the related findings, this research evidenced that US and HPH treatments represent effective technological treatments for the reduction of cooking water viscosity and thus were promising technologies for tackling the continuous cooking procedure issue in pasta cookers.

Strategies for continuous cooking procedure optimization in pasta cookers

Consumers more and more rise the expectations in terms of the quality of food, which has to be promptly served always fresh-like (Linnemann et al., 2006). Kitchen operators ask to the appliance for stress inputs minimization, safety, high efficiency and productivity (Ahn, Kim, & Jeong, 2006). All these needs are reported to the engineers in the manufacturing for being transformed into engineering metrics.
To tackle the issue of continuous cooking procedure in pasta cookers and please kitchen operators and engineers during daily workload and appliance development in the manufacturing, respectively, two strategies were proposed. The strategy presented in Chapter 5 regarded the formulation of the technology concept of an US bath system in the pasta cooker (TRL 2). Even though principles are observed, such implementation needs to be validated (TRL 3) taking into account frequency, amplitude, well volume, as main process parameters for US treatment. Indeed, the findings reported in the part I where obtained using a direct method of sonication on laboratory scale that have now to be proved on industrial scale prototype. However, implications for the professional appliances industry can already be formulated. By considering the whole range of appliances available in the Electrolux Professional portfolio, automatic cycles could be developed. Considering lifting baskets, the US bath system could be activated on the upper raw transducers during pasta cooking for foam breaking and on the middle raw for cooking water treatment in between batches. This means to implement an automated activation system that switches on the middle raw when baskets are raised and the upper raw when baskets are lowered. When the appliance

is switched off and the baskets are lowered in the well, the lower raw transducers can work as a “cleaning aid”, and this can be also automatized considering the cooking temperature and power rating as threshold for activation. So, physical effort by kitchen operators is greatly reduced with better cleaning results and savings of time, water and costs (Otto et al., 2011). The strategy proposed in Chapter 6 aimed at optimizing the cooking procedure by managing the power rating directly on the appliance. To this regard, pasta cookers could also benefit from the addition of an automatic “simmer mode”. Many restaurants leave the pasta cooker in a boil state, which can run the appliance at a maximum power duty cycle, even if the appliance is working not cooking. An automatic setback that reduces the water temperature by managing the power rating to after a predetermined cook time could reduce appliance energy and water use by 60% (Spoor et al., 2014). Finally, the strategy works also for accident prevention about rolling boil and slippery surfaces, while reduces the stress inputs of manually and empirically managing the power supply for preventing foam formation.

MAIN CONCLUSIONS

This research provides new insight into pasta cooking by taking the continuous cooking procedure in professional appliances as study case. The novelty and interest of this work derives from the consistent framework built using food science knowledge and techniques, and its upfront confrontation to the complexity of the industrial (food service) environment. The disciplinary gap between engineers and kitchen operators, indeed, has been lowered by using traditional methods, used both in the food service and in the food science laboratory, and conventional and unconventional technologies whose aim was tackling the issue related to continuous cooking in pasta cookers.

The constant effort in establishing a food science-based dialogue among engineers and kitchen operators is particularly evident in the association of qualitative information with quantitative data, which represents an effective strategy to improve food science rationale in professional appliance development in the manufacturing and use in the professional kitchen.

Even if this work serves first the purpose of solving an actual industrial problem, it expands the understanding on pasta cooking, bridging the gap between theoretical knowledge and professional practice. On one side, indeed, the research answers to the market need for food scientists who integrate food science and engineering knowledge in developing new procedures and products. From this work clearly emerges that food science represents a competitive advantage for the food service sector, being the driver for product innovation. On the other hand, in the academic context, the proposed approach allows a professional-based knowledge about pasta cooking related to professional appliances.

FUTURE DIRECTIONS

To clarify the effect of continuous cooking on pasta and cooking water properties and further improve the relevance of optimization strategies to the food service context, some of the future directions of research could include the following topics.

- Evaluate the influence of cooking water physico-chemical characteristics during continuous cooking of pasta in pasta cookers. Cooking water solid content and pH were proved to be important factors during continuous cooking. However, available data on the combined effect of tap water (minerals) and cooking water (solid content and pH) composition on cooking properties of pasta during continuous cooking are still scarce.
- Validation of US bath system. Laboratory scale studies and formulation of the technology concept on industrial scale are fundamental steps (TRL 1 and 2) for finding solutions to industrial issues, but prototyping is crucial for a better understanding of the potential benefits of unconventional technologies on foam breaking, viscosity reduction and cleaning optimization.
- Sensory analysis of spaghetti cooked quality. During standard continuous cooking and upon optimization strategies implementation, a food science-based dialogue also with the consumer can be established by performing sensory analysis.

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LIST OF PUBLICATION RELEVANT TO THIS PH.D RESEARCH ACTIVITY

Diamante, G., Peressini, D., Simonato, M., & Anese, M. (2019). Effect of continuous cooking on cooking water properties and pasta quality. *Journal of the Science of Food and Agriculture*, 99(6), 3017–3023.

LIST OF SUBMITTED AND IN PROGRESS MANUSCRIPTS

Diamante, D., Deleu, L., Simonato, M., Anese, M. Delcour, J. New insight into the effect of continuous cooking on pasta and cooking water properties. Under submission.

Diamante, D., Peressini, D., Simonato, M., Anese, M. Effect of ultrasounds and high pressure homogenization on cooking water properties of continuously cooked spaghetti. Draft under preparation.

Diamante, D., Peressini, D., Simonato, M., Anese, M. La cottura continua nei cuocipasta professionali: problematiche e possibili strategie. Draft under preparation.

CONTRIBUTIONS TO NATIONAL CONFERENCES

Diamante, G. *New insights into pasta cooking: the continuous cooking procedure in professional appliances*. In Proceedings of "XIV Workshop on the Developments in the Italian PhD Research on Food Science, Technology and Biotechnology", pp. 398-404, Firenze, Italy, from 11/09/2018 to 13/09/2019*.

Diamante, G. *Continuous cooking effect on pasta quality in the food service*. In Proceedings of "XXIII Workshop on the Developments in the Italian PhD Research on Food Science, Technology and Biotechnology", pp. 147-148, Oristano, Italy, from 19/09/2018 to 21/09/2018.

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