Journal of Food Engineering 187 (2016) 114–123

Contents lists available at ScienceDirect

Journal of Food Engineering

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

Processing of barley grains in a continuous vibrating conveyor

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ARTICLE INFO

Article history:
Received 9 October 2015
Received in revised form
8 April 2016
Accepted 13 April 2016
Available online 14 April 2016

Keywords:
Vibrating conveyer
Residence time distributions
Particle flow
Heat transfer

ABSTRACT

A novel tubular industrial apparatus for the surface pasteurization of particles has been studied. Particles are conveyed through a helical pipe by vibrations created by off-balance motors. The residence time of barley grains was characterized. The behaviour of the system was a function of motor angle and motor speed. The residence time could vary up to 21% during one experiment of 2 h (20°, 740 rpm). However, ranges of processing conditions were identified that produce stable operation and thus effective pasteurization of product. In some cases, residence time increased by up to 7% of the initial value over consecutive experiments (40°, 710 rpm). Some reasons for this phenomenon have been proposed and tested. The formation of a powder layer inside the pipe has been proven to affect the residence time of barley grains. A simple model for pasteurization of particles has been developed to characterise the impact of variation in residence time on microbial inactivation.

1. Introduction

Thermal processing is a major part of the food industry; it is carried out for a range of reasons, both to improve product quality but also to enhance the microbiological safety of products. It is essential to ensure that the thermal process does not damage the product. Careful selection of the correct temperature-time combination of the thermal process is thus critical in determining the success of the overall product.

In recent years, foodborne pathogen infections associated with the consumption of low water activity products such as almonds, peanut butter, or powdered infant formula have received increased attention (Beuchat et al., 2013). The primary pathogen of concern is *Salmonella* spp. (Codex Alimentarius Commission, 2013; Beuchat et al., 2011). Between 2000 and 2011, at least 1771 people were affected in Australia, New Zealand, Canada, USA and Europe by outbreaks of such infections (Beuchat et al., 2011). Even though a low water activity generally inhibits microbial growth, cells can remain viable at these conditions (Penaloza Izurieta and Komitopoulou, 2012; Mattick et al., 2000). Additionally, microorganisms can be more resistant to heat in matrices with reduced water activity (Barrile and Cone, 1970; Penaloza Izurieta and Komitopoulou, 2012; Podolak et al., 2010; Villa-Rojas et al., 2013). Depending on food preparation, portion size, and individual circumstances of the consumer, viable pathogenic cells can cause sickness. Consequently, measures like processing interventions that lead to a minimum 4 log reduction of Salmonella in almonds have been adopted to ensure the safety of these products (Almond Board of California, (2007)). Some kinetic data for relevant organisms is given in Table 1.

Technological solutions to the pasteurisation/sterilisation of particulates have focused on steam pasteurisation. This has proven to be more efficient than dry heat in inactivating microorganisms in low water activity, particulate products. Reasons include:

- Steam can penetrate small areas and cavities within the particles. Furthermore, steam has a greater specific enthalpy at 100 °C than water at that temperature and it increases the temperature of the particle's surface rapidly due to steam condensation (Lee et al., 2006).
- Microorganisms are more thermally sensitive at the increased moisture content on the product surface caused by steam condensation (Chang et al., 2010). Proteins are more stable at low water contents in the cells (Podolak et al., 2010; Neetoo and Chen, 2011). Hence, at low water content more energy is needed to unfold the protein structure, which leads to increased heat resistance (Podolak et al., 2010). In comparison, moist thermal treatment potentially destroys the proteins (Neetoo and Chen, 2011). Consequently, disulphide bonds and hydrogen bonds in

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http://dx.doi.org/10.1016/j.jfoodeng.2016.04.010

Table 1
Kinetic data for microorganisms relevant to low moisture products.

Microorganism	Product	D-value [min]	z-value [°C]	Conditions	Source
Salmonella Tennessee	Toasted oat cereal	$D_{85} = 133.9$ $D_{105} = 2.4$	11.86	Dry heat treatment	(Chick, 2011)
Salmonella Agona		$D_{85} = 117$ $D_{105} = 5.2$	14.90		
Salmonella Enteritidis PT 30	Almond flour	$D_{80} = 1.63$	8.28	Dry heat treatment $a_w = 0.610$	(Villa-Rojas et al., 2013)
Salmonella weltevreden	Wheat flour	$D_{60-62} = 875$ $D_{63-65} = 29$	15.2 53.9	Initial $a_w = 0.4$ Initial $a_w = 0.5$	(Podolak et al., 2010)
Salmonella Enteritidis PT 30	Almonds	$D_{60} = 2.6$ $D_{80} = 0.75$	35	Hot water treatment	(Harris et al., 2012)
Salmonella Enteritidis	Almonds	$D_{93} = 0.27$	–	Steam treatment	(Lee et al., 2006)

the surrounding protein weaken and break (Podolak et al., 2010).

The principle of controlled condensation is the base of a steam pasteurisation process. The goals of such a process are:

- The formation of a thin layer of moisture on the surface of each particle;
- Maintenance of those conditions for sufficiently long for the inactivation of pathogens;
- A short drying step in the end of the process to provide a safe, dry, and stable product.

Several methods are used for this purpose (Napasol, 2015; ETIA, 2014; Buhler, 2014). In batch systems, moist heat and reduced pressure are common to ensure high quality and safe products (Napasol, 2015; Buhler, 2014). Continuous systems such as electrical heated screw conveyors are also implemented (ETIA, 2014). The continuous system presented in this study (Revtech, 2015) conveys particles up a helical pipe by vibrations. The pipe is heated directly by resistive heating in which electrical current flows through the pipe at low voltages (approx. 30 V). The combination of the vibrations of the helix and a relatively low bed height of the product are considered to deliver quick and even heat transfer from the heated walls of the pipe to the particles. Steam can be added and extracted at various points throughout the process.

The design of any process to deliver a microbial reduction requires understanding of the variation of residence time of material within the process. In the process studied here, understanding of the particle motion and the accurate predictability of the residence time are critical for the design of a thermal process that results in high quality and safe products. The aims of this study were:

- To investigate the influence of various process parameters on the residence time of barley grains through the equipment, and
- To identify areas where the residence time is stable with time, and
- To develop a theoretical model to estimate the pasteurising effect of the process

Parallel work has studied the use of the device to process flour (Keppler et al., 2015).

2. Materials and methods

2.1. Material

One batch of 200 kg of barley grains was used for the experiments. This was provided by Campden BRI (Gloucestershire, UK).

The median (by volume) of the particle size was calculated to be 5210 ± 430 μm with a sphericity of 0.81 ± 0.01 on a QICPIC system (Sympatec GmbH, D) with a measurable particle size of 30 μm–10,000 μm (Gradis disperser, M9 lense). The bulk density was measured to be 687 ± 2 kg/m^3.

2.2. Equipment

The equipment used for the experiments is a continuous, thermal processing unit provided by Revtech (Loriol-sur-Drôme, France). It consists of three major parts, a hopper, a heating spiral, and a cooling spiral. In this study only the hopper and the heating spiral were used for simplicity. As shown in Fig. 1, particles are conveyed by a screw feeder (B) from the hopper (A) into the spiral. It is a helical, steel pipe (C) with an internal diameter of 84.5 mm, a slope of 2.83° to the horizontal, and a length of approx. 34.4 m. It is possible both to heat the pipe by resistive heating and to inject steam, but in this case, no thermal treatment was applied. The screw feeder speed is controlled by a check-weigher to keep the mass flow constant. This controls the overall particle flow, whilst the behaviour in the tubing is controlled by the vibrations of the motors. Two off-balance motors (D) are attached on opposite sides of the spiral and at an adjustable angle with the horizontal. They create vibrations of different amplitudes and frequencies. The vibrations can be controlled by changing:

- *Motor angle*. The movement of the motor is perpendicular to the motor axis. Adjustment of the motor angle β affects the velocity components of the motors in horizontal and vertical direction. This is shown in Fig. 2 and the components are defined as equations (1) and (2). With increasing angle β, which ranges

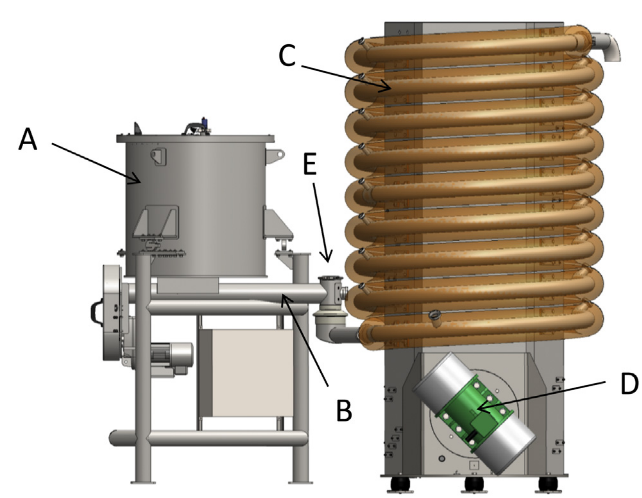

Fig. 1. Experimental setup: Hopper (A), screw feeder (B), insulated helical pipe (C), motor at an angle with the horizontal (D), insertion point for coloured grains (E).