Journal of Food Engineering 160 (2015) 34–41

Contents lists available at ScienceDirect

Journal of Food Engineering

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

Production of structured soy-based meat analogues using simple shear and heat in a Couette Cell

Georgios A. Krintiras [a], Jesse Göbel [a], Atze Jan van der Goot [b], Georgios D. Stefanidis [a,c,*]

[a] Process & Energy Department, Mechanical, Maritime & Materials Engineering Faculty, Delft University of Technology, Leeghwaterstraat 39, 2628 CB Delft, The Netherlands
[b] Food Process Engineering Group, Wageningen University and Research, P.O. Box 176700 AA, Wageningen, The Netherlands
[c] Chemical Engineering Department, Katholieke Universiteit Leuven, Willem de Croylaan 46, 3001 Leuven, Belgium

ARTICLE INFO

Article history:
Received 25 October 2014
Received in revised form 20 January 2015
Accepted 16 February 2015
Available online 27 March 2015

Keywords:
Fibrous structure
Meat analogue
Shear
Soy
Gluten
Plant protein

ABSTRACT

A Couette Cell device was employed to provide proof of concept for the production of structured meat analogues by application of simple shear flow and heat to a 31 wt% Soy Protein Isolate (SPI)–Wheat Gluten (WG) dispersion. Three relevant process parameters (temperature, time and rotation rate) were varied over a range of realistic values (90–110 °C, 5–25 min and 5–50 RPM, respectively). Layer- or fibre-structured products with high stress and strain anisotropy indices have been demonstrated. Fibrousness is favoured at temperatures over 90 °C and under 100 °C, whereas the role of process time and rotation rate is not critical. Simultaneous application of simple shear and heat is the key to obtaining structured plant protein-based products. The Couette Cell concept is scalable and can enable continuous operation. On this ground, it appears as a realistic option for production of meat analogues at commercial scale.

1. Introduction

With an increasing world population of nearly 7 billion people there is a growing demand for food supply. A plant protein-based diet can partially address the problem of food crisis and animal protein malnutrition in several developing countries. Further, in developed countries, increasing awareness of animal welfare and environmental protection has shifted the daily food consumption towards plant-based diet as well. Moreover, plant proteins provide desirable functional properties, such as solubility, viscosity, water and oil retention, foam formation, emulsification and gelation. In Western diets, significant reduction in meat consumption (up to 40%) is possible without risk of lack of micro-nutrients normally supplied through meat products. Therefore, an introduction of new alternative forms of food products and room for development of an attractive market around plant protein-based products in food industry is needed (Boye et al., 2010; Rodrigues et al., 2012). Meat analogues created from plant-based materials can form one class of these products, which will be accepted by consumers provided that they have pronounced fibrous structure and are competitive in price compared to meat. The latter prerequisites simple technology for making the products (Hoek et al., 2011).

Currently, extrusion (Lin et al., 2002; Thiébaud et al., 1996; Yao et al., 2004) and spinning (Huang et al., 1995; Rampon et al., 1999; Suchkov et al., 1988) are the main techniques available to make anisotropic structures. However, these techniques come with some disadvantages. Spinning produces large waste water streams. In addition, the necessity for low pH, high salt concentrations and chemical additives makes the process complex (Manski et al., 2007b). Extrusion, which is the current best technology for production of meat analogues, applies thermo-mechanical treatment using high temperatures and shear rates inside the barrel/screw region resulting in melting of the protein suspension and intensive mixing. Only at the die region, where the mixture is cooled down and simple shear flow is present, structure formation can occur (Riaz, 2000). This process was first demonstrated in 1797 by Josef Bramah, England, who was the first to apply the extrusion principle using a hand-operated piston press to extrude seamless lead pipes for use in guns and rifles (Blackmore, 1986). The use of extrusion for high moisture applications (40–80%) has been reviewed by Cheftel et al. (1992). Cheftel reported that application of a twin-screw extruder combined with a long cooling die to Soy Protein Concentrate (SPC), or mixtures of Soy Protein Isolate (SPI) and 5–10% vital wheat gluten (WG) enabled the formation of anisotropic structures with layers and coarse fibres oriented in

* Corresponding author at: Chemical Engineering Department, Katholieke Universiteit Leuven, Willem de Croylaan 46, 3001 Leuven, Belgium. Tel.: +32 16 32 23 48.
E-mail address: georgios.stefanidis@cit.kuleuven.be (G.D. Stefanidis).

http://dx.doi.org/10.1016/j.jfoodeng.2015.02.015
0260-8774/

the direction of the flow through the die. However, it was very difficult to extrude and structure pure SPI.

Recently, a new technique based on the concept of flow-induced structuring (Manski et al., 2007b, 2008; Peighambardoust et al., 2004) was introduced. For this purpose, a cone–cone device based on a cone–plate rheometer was developed which is referred to as Shear Cell. The top cone is stationary while the bottom cone rotates. Both cones can be heated and cooled with the use of an oil bath. Contrary to extrusion, the deformation inside the device is well defined and constant upon processing. Due to a combination of simple shear and heat, proteins are aligned forming fibrous structures. (Manski et al., 2007b, 2008) reported that it is possible to fibrilize dairy proteins (calcium caseinate) in a Shear Cell. However, the shear rate in the Shear Cell is not constant over the entire protein sample volume due to the gradually increasing distance between the cones along the radius. Most importantly, the scalability of this configuration is limited, which limits its applications to lab-scale testing.

In this work, a Couette Cell is explored as an alternative *scalable* geometry. The Couette Cell design favours increased product thickness and capacity by simply increasing the cylinders' size and length. Additionally, the Couette Cell can be potentially operated in a continuous mode in the future. The device was originally developed to study the behaviour of dough under simple shear flow and was not optimized for operation at elevated temperatures (Peighambardoust et al., 2007). After several design upgrades of the original device to improve heat management and material handling, the Couette Cell has been used in this work to shear a blend of plant proteins. A limited parametric study, with respect to process temperature, process time and rotations per minute (RPM) of the inner cylinder, was performed to prove the process concept. The products were characterized by means of visual inspection, texture analysis/tensile stress and scanning electron microscopy (SEM). It is remarked that the purpose of the experimental study was not a full optimization of the operating conditions, but the first demonstration of the potential of a Couette Cell to make anisotropic plant protein-based structures under mild process conditions.

2. Materials and methods

2.1. Materials

A blend of soy protein isolate (SPI) (SUPRO EX37 HG IP, Solae, USA) and vital wheat gluten (WG) (VITEN, Roquette, France) was used. In the event of SPI, the protein content was 90%, while gluten had a protein content of 81% based on a nitrogen-to-protein conversion factor of 6.25, measured with the Dumas method. Sodium chloride, referred to as salt hereafter, was also used, as it has been reported that it may enhance the formation of anisotropic structures (Grabowska et al., 2012).

2.2. Experimental set-up – Couette Cell

The Couette Cell is shown in Fig. 1. It is based on the common concentric cylinder rheometer concept. The device is connected to a rheodrive unit (Haake PolyLab QC, Thermo Fisher Scientific, Karlsruhe, Germany), which is used to record temperature and torque while keeping the angular velocity of the rotating inner cylinder constant. The outer cylinder remains stationary. Both the inner and outer cylinders are heated by means of oil. The sample material is placed in the space between the two cylinders; this space is called *shearing zone*. The temperature in the shearing zone is measured in two positions in the middle of the total height.

Two oil baths are used; one "hot" oil bath to heat up the Couette Cell before and during an experiment and one "cold" oil bath, at

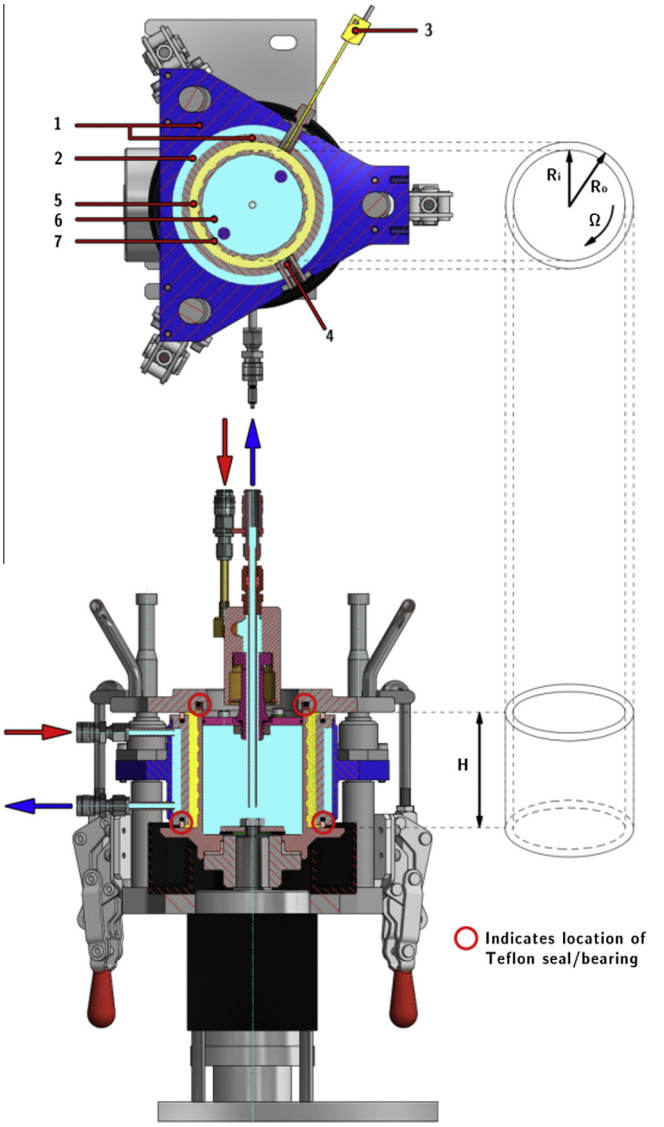

Fig. 1. Horizontal (top) and vertical (bottom) cross sections of the Couette Cell. 1 – Outer cylinder; 2 – heating chamber of outer cylinder; 3 – PT100 temperature sensor; 4 – filling opening and location of J-type thermocouple; 5 – shearing zone; 6 – heating chamber of inner cylinder; 7 – inner cylinder. R_i (radius of inner cylinder) = 0.0425 m, R_o (radius of outer cylinder) = 0.0485 m and H (height of both cylinders) = 0.085 m.

60 °C, to cool the Couette Cell down after shearing. A PT100 temperature sensor is placed in the wall of the outer cylinder with its tip located at the inner wall of the outer cylinder. The PT100 is connected to the hot oil bath to allow temperature reading and control of the Couette Cell. The temperature of the hot oil bath is controlled by the Lauda Wintherm software (Lauda DR. R. Wobser GmbH & Co. KG, Lauda-Königshofen, Germany) on a PC connected to the hot oil bath via an R232 connector. A J-type thermocouple is placed at a position closer to the inlet of the heat transfer fluid in the middle of the plug to seal the filling hole (see Figs. 1 and 2). The J-type thermocouple was calibrated with a dry block calibrator (T-350P, PRESYS) and a high precision thermometer (F252, ASL). The incoming flow of the heat transfer fluid is split before it enters the Couette Cell, so the inner and outer cylinders are heated simultaneously (in parallel).

An important aspect of the Couette flow is that the velocity gradient and shear stress are constant throughout the flow domain provided no slip at the walls. The absence of wall slip is one of