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Compression heating of selected pressure transmitting fluids and liquid foods during high hydrostatic pressure treatment

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Abstract

Three pressure transmitting fluids (water, ethylene glycol, and ethanol) and three liquid foods (orange juice, whole, and skim milk) were pressurized at 100–400 MPa and at 5, 20 and 35 °C, using different compression rates (100, 200, and 300 MPa/min) to evaluate the adiabatic heating phenomena during high hydrostatic pressure (HHP) processing. A pressure vessel (3 L volume) in which liquid foods could be introduced directly was used to demonstrate the compression heating phenomena in large-scale commercial conditions.

The highest and second highest compression heating values were observed for ethanol and ethylene glycol, respectively. Orange juice, whole, and skim milk showed similar compression heating values with water. The results revealed that as the initial temperature of the samples increased, compression heating values also increased. In general, as the pressure level increased, the temperature increase per 100 MPa decreased only for ethanol and ethylene glycol. The compression rate also had an impact on the compression heating values of ethanol and ethylene glycol. However, water and liquid foods (that contained high amount of water) were not affected by the compression rate within the range studied (100–300 MPa/min).

An empirical response surface model was developed to calculate the temperature increase of the samples during HHP processing at different pressure levels and initial temperatures. In principle, the proposed model could also be used to predict the compression heating values of other foods under the combined effect of high pressure and temperature.

Keywords: High hydrostatic pressure; Compression heating; Pressure transmitting fluids; Response surface model

1. Introduction

High hydrostatic pressure (HHP) processing is an alternative for pasteurization of food products as an emerging preservation method. The treatment of foods or food ingredients by HHP is accompanied by an increase in temperature in the treated volume. This phenomenon is induced by compressive work against intermolecular forces. The temperature increase on account of compression can be theoretically calculated by using Eq. (1) (Denys, Van Loey, & Hendrickx, 2000).

$$\frac{dT}{dP} = \frac{T \cdot \alpha}{\rho \cdot C_p} \quad (1)$$

where T is temperature (K), P is pressure (Pa), ρ is density (kg/m^3), C_p is heat capacity of the food substance at a constant pressure (J/kg K) and α is thermal expansivity (K^{-1}). This equation is strictly applicable to small pressure changes and isothermal compressions. Moreover, the compression rate should be less than 0.1 MPa/s, so around 1 h is required to reach 350 MPa, which is not convenient for the food industry (Otero & Sanz, 2003). Therefore, it is almost impossible to avoid compression heating during HHP treatment whatever the structure of the equipment is.

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In recent times, studies related to compression heating of different pressure transmitting fluids and food substances by HHP are gaining interest (Balasubramanian & Balasubramaniam, 2003; Patazca, Koutchma, & Balasubramaniam, 2007; Rasanayagam et al., 2003). Patazca et al. (2007) and Rasanayagam et al. (2003), have determined compression heating values at very fast (<3 s) compression rates, as the vessel size used was very small (about 50 mL). Using small vessel size may not exactly reflect the same compression heating behavior of the samples as the large-scale commercial equipment. Moreover, a thermocouple should be inserted into the package in which the sample is placed and this may cause different compression heating value measurements between the sample in the package and the pressure transmitting fluid, as they have different physical properties. This will eventually lead to deviations from temperature uniformity of the sample. Therefore, the compression heating values of pressure transmitting fluids and food substances over a range of pressure, temperature, and compression rate must be studied.

The objectives of this study are: (i) to determine the compression heating values of different pressure transmitting fluids (water, ethanol, and ethylene glycol) and liquid foods (whole milk, skim milk, and orange juice) during HHP treatment in a large vessel; (ii) to develop a mathematical model to describe the temperature increase of the samples at different pressure levels and initial temperatures.

2. Materials and methods

2.1. Pressure transmitting fluids and liquid foods

Water, ethanol (99.5%, J.T. Baker, Deventer, Holland), and ethylene glycol (99%, Sigma Aldrich, Steinheim, Germany) were used as pressure transmitting fluids. Whole milk, skim milk, and orange juice were obtained from a local market (Bordeaux, France).

2.2. HHP equipment and experiments

Pressurization (100, 200, 300, and 400 MPa) was carried out using a computer controlled high pressure unit with a 3 L sample vessel (diameter: ~10 cm, height: ~40 cm), capable of operating up to 800 MPa, designed by NFM-Technologies (Le Creusot, France) and FRAMATOME (Paris, France), marketed by CLEXTRAL (Firminy, France). Ideally, pressures should not be greater than 350 MPa, to reduce capital investment costs of HHP processes, although successful commercial applications have used higher pressures than this (Jordan, Pascual, Bracey, & Mackey, 2001). That is why the maximum pressure has been selected as 400 MPa in this study.

The compression rates were 100, 200, and 300 MPa/min. These values were also applicable to commercial large-scale applications. The decompression rate was set to its fastest value (300 MPa/min), as most commercially available HHP systems had fast decompression rates. Prior to

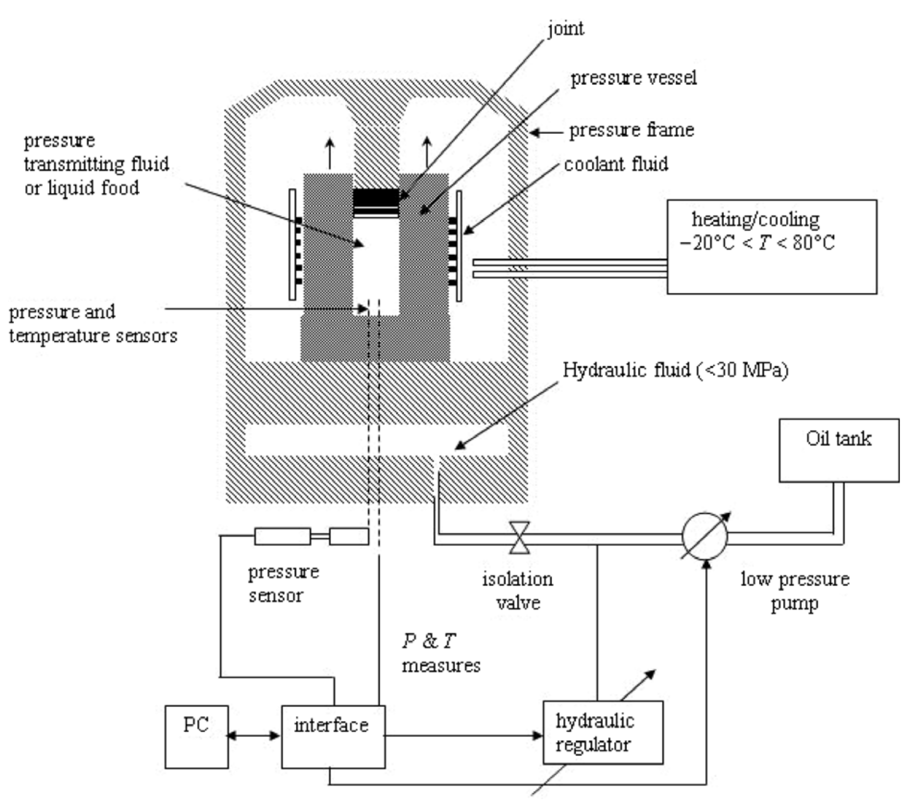

Fig. 1. Schematic diagram of high pressure equipment.