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A computational study on heat transfer characteristics of particulate canned foods during end-over-end rotational agitation: Effect of rotation rate and viscosity

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ABSTRACT

End-over-end (EoE) rotation is a common type of mechanical agitation used in canning sterilization process to increase heating rates, enabling reductions in processing time and energy use and improving quality. During EoE rotation, cans are rotated around a circle in a vertical plane for improved mixing and heat transfer. The rotation makes it difficult to characterize time-temperature history of the process by an experimental set-up. Even though remote temperature logging methodologies have been developed, the general approach in the literature was to develop empirical approaches for heat transfer coefficient. Since time-temperature history of the process must be known to determine process lethality, changes in quality attributes and further optimize the process, computational modeling of EoE dynamics is of great interest. Therefore, the objective of this study was to present computational modeling of an EoE process for canned particulate products to provide a detailed insight of the EoE rotation. This study included a 3-dimensional modeling using a volume of fluid (VOF) multiphase approach with rotating mesh. Movement of entrapped headspace dynamics via the effect of liquid viscosity suggested a possible explanation about the complex non-linear effect of rotation rate on heat transfer enhancement. Effect of viscosity and rotational speed were determined for overall understanding of heat transfer to give insights of the EoE rotation for canning particulate food products.

1. Introduction

Canning is a significant operation in food industry, and it is still one of the most effective way of thermal processing to preserve food products. Using rotating retorts is a common way in canning industry to create agitation and enhance heat transfer rate in liquid and particulate canned foods for shorter processing times with improved sensory and nutrient quality. Agitation in a rotational process might be carried out by end-over-end rotation (EoE) where the can symmetry axis lies in the rotation plane or free-axial where the can symmetry axis is horizontal and perpendicular to the rotation plane (Hughes et al., 2003).

EoE rotation is quite common in batch retorts while axial rotation is preferred in continuous systems (Dwivedi and Ramaswamy, 2010). It was proposed firstly by Clifcorn et al. (1950). In this process, the cans are rotated on a circular trajectory in a vertical plane while the movement of headspace bubble improves mixing. The flow dynamics, in addition to the natural convection based flow evolution, develops during

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the agitation, and it involves complex interactions of centrifugal, gravitational buoyancy, Coriolis and viscous forces (Boonpongmaee and Makotani, 2009). Distortions in velocity and temperature profiles are induced with rotation and improve upon flow and heat transfer (Hamady et al., 1994). Naveh and Kopelman (1980) compared the effect of rotation for axial and EoE cases with respect to heat transfer coefficient in a high viscosity liquid model system. Price and Bhowmik (1994) evaluated the heat transfer coefficient change in canned liquid foods undergoing horizontal and vertical rotation. Dwivedi and Ramaswamy (2010) compared the heat transfer rates obtained by EoE and axial rotation modes using a Newtonian liquid and reported the significantly higher heat transfer coefficients in the axial mode rotation. Rattan and Ramaswamy (2014) provided detailed information on comparison of EoE and axial rotation mode effects on process lethality and quality changes. However, the effect of rotation rate was reported not to improve the heating rates always (Knap and Durance, 1998). Tutar and Erdogdu (2012) and Erdogdu and Tutar (2012) pointed out the negative effect of rotation rate for axial-rotated cans where viscosity effects for this behavior were underlined. To fulfill the requirement of a correct knowledge of time-temperature history during a sterilization process to satisfy the pre-determined minimum heat treatment in the form of process lethality (F_0), understanding of EoE dynamics is very important, and unfortunately this process is rather difficult to be characterized by an experimental set-up. In the case of canning, however, validation of the process performance is a significant process step to ensure a safe process.

There has been a certain progress in the remote temperature logging to validate the thermal processing systems. Use of temperature and pressure data loggers have certain deficiencies due to their volume occupying in the can and hence to affect the temperature distribution. Marra and Romano (2003) demonstrated the influence of the relative dimensions of a wireless temperature sensor compared to the can size on temperature change in the given system. For this purpose, the use of active transmitted data loggers, as an RFID wireless data logger, has also been introduced to validate a canning rotation process. In addition to the requirement that the logger would not affect the heat transfer within the system, the location of the coldest region must be known to locate the wireless logger for a validation study. This issue becomes important especially when the temperature distribution within the system is not homogeneous as in the case of food products. Therefore, besides the experimental studies, computational approaches have gained their effect for process validation and to ensure a safe and optimized process. With this approach, optimization studies and what-if scenarios for the process can also be carried out, and the results might be used for process improvement purposes. The optimization scenario can specifically focus on maintaining the quality attributes during the process and reducing the energy costs.

In addition to the experimental heat transfer studies based on liquid filled cans, computational studies were also carried out for particulate canned food products where the objective was to determine the particle-liquid heat transfer coefficient within the system. Stoforos and Merson (1990, 1995) developed mathematical approaches to estimate the heat transfer coefficients in liquid/particulate canned foods for still and agitation cases. Deniston et al. (1987) determined liquid-particle heat transfer coefficient in an axially rotating can, and Sablani and Ramaswamy (1995, 1999) used the same approach for EoE processing of cans containing liquid particle mixtures. In these related studies, the viscosity effects were highlighted. Meng and Ramaswamy (2005) demonstrated that the rotation speed of EoE processing and process temperature were the most significant factors in affecting the fluid-particle heat transfer coefficient while the rotation radius effect was not significant in a particulate non-Newtonian fluid system. Later, Meng and Ramaswamy (2007a) reported an increase in heat transfer coefficient in canned particles with decrease in viscosity in a Newtonian liquid system during EoE rotation. Developing dimensionless correlations and determining particle-liquid heat transfer coefficients were the common approach for this purpose (Anantheswaran and Rao, 1985; Sablani et al., 1997; Garrote et al., 2006; Meng and Ramaswamy, 2005, 2006, 2007a,b; Dwivedi and Ramaswamy, 2010).

Besides determining heat transfer coefficient and developing dimensionless correlations, Abdul Ghani and Farid (2006) applied CFD to analyze the thermal sterilization of solid-liquid food mixtures; Rabiey et al. (2007) carried out a 3D simulation study for heat transfer and liquid flow during sterilization of large particles in a vertical can; Kiziltas et al. (2010) determined the temperature distribution in the canned peas using a CFD approach where natural convection effects on heat transfer and temperature changes were discussed in detail. This study was followed by Dimou and Yanniotis (2011) for asparagus in brine (4%); Dimou et al. (2013) for thermal processing of table olives in brine (4%); Dimou et al. (2014) for determining the effect of particle orientation during thermal processing of peach halves; Cordioli et al. (2015) for CFD modeling and

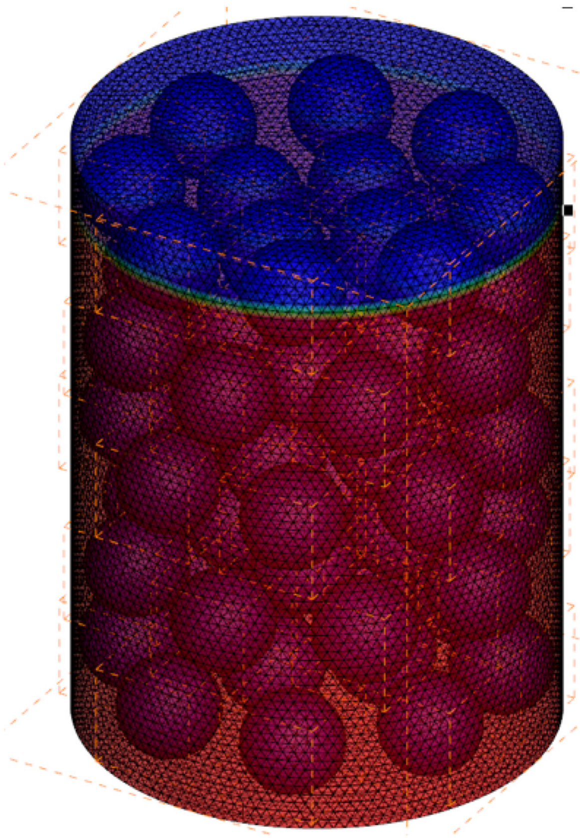

Fig. 1 – Computational geometry with 949,300 cells and location of the headspace (shown with blue) at the beginning of the rotational process. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)