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Modification of a static steam retort for evaluating heat transfer under reciprocation agitation thermal processing

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ABSTRACT

A lab-scale reciprocating agitation retort was developed by modifying an existing conventional vertical static retort to include a reciprocating mechanism consisting of: (i) a reciprocating cage; (ii) a slider-crank assembly; and (iii) a permanent magnet motor. Mechanism was provided to control the amplitude (3–30 cm) and frequency of reciprocations (0–5 Hz). 307 × 409 cans filled with 80% glycerin to 10 mm headspace and equipped with a single particle were processed under different operating temperatures (110–130 °C), frequencies (0–4 Hz) and amplitudes (5–25 cm). Heat transfer analysis of the system revealed a very uniform and rapid heating scenario with 52–87% reduction in the equilibration time of the cold-spot and 2–7 times enhancement in the values of heat transfer coefficients. Consequently, process time required to achieve lethality of 10 min, reduced from 45 min to 17–24 min. Reciprocation processing also resulted in 26–36% reduction in quality-deterioration index (cook-value/lethality), showing potential to deliver high quality products.

1. Introduction

Owing to the recent surge in consumer demands for high quality foods, the thermal processing industry has felt a growing need for developing systems which can provide rapid heating conditions for inactivating microorganisms causing public health and spoilage concerns. This is primarily because rapid and uniform heating conditions permit the product to reach the processing temperatures faster, and thus, the required process can be accomplished in a shorter time. The shorter process time, while satisfying the sterility requirements, reduces the thermal damage to food color, texture and nutrients resulting in a better quality. Moreover, short process cycles also help to increase the process efficiency and enhance the production capacity of the facility.

Forced convection obtained through agitation of the containers during thermal processing, has been used to provide rapid heating conditions, particularly in convection-heating products, to promote better heat transfer and to obtain better quality of food products (Anantheswaran and Rao, 1985). Agitation also prevents different ingredients and phases in the food product from separating from each other during thermal processing (Deniston et al., 1992; Dwivedi and Ramaswamy, 2010a). A number of agitating cookers have been described in the patent literature (Lowe and Poindexter, 1952; Oharenko, 1958; Prickett, 1958; Evans, 1992; Veltman, 1995; Silvestrini, 2008) and they all serve the common objective of increasing the rate of heat penetration and making the temperature distribution within the can more uniform. Commercial rotary retorts, like Sterilmatic (FMC Corp., San Jose, CA), Steristar (Malo Inc., Tulsa, OK), Rotomat (Stock America, Inc., Milwaukee, WI) etc., provide agitation through rotation of cans in end-over-end or axial mode.

Clifcorn et al. (1950) first suggested the use of rotation to increase heat transfer to canned foods. They proposed the use of EOE (end-over-end) mode in which cans rotate around a circle in a vertical plane. In the axial mode, cans are moved through a rotating helical coil moving continuously from one to the other end of the retort. The cans must have a headspace for effective agitation. As the can rotates, the headspace bubble moves along the length of the can and brings about agitation of the can's contents. Sablani and Ramaswamy (1996) noted that after a certain speed, when centrifugal and gravitational forces acting on the can were equal, particles inside the can start accumulating at the edge of the can and thus reduce the movement of the headspace within the can. Hence, rotary agitation suffers from the disadvantage that after a certain speed of rotation, the overall heat transfer coefficient (U) and fluid-to-particle heat transfer coefficient (h_{fp}) start decreasing. Biaxial mode of agitation was evaluated by Dwivedi and Ramaswamy (2010a), in which the cans changed the direction of rotation twice during one revolution of the cage. This neutralizes

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the effect of centrifugal forces by the extra turbulence created due to changing of the direction of motion. Thus some improvement in heat transfer was possible using rotary agitation, although centrifugal forces were a limiting factor.

Lateral reciprocation agitation of containers during thermal processing can potentially impart agitations that do not subside with an increase in intensity. Although, the first reciprocating cooker was patented by Gerber (1938), not much scientific research has been carried out in this area since then. Walden (1999) acquired another patent for a retort utilizing reciprocation agitation of the containers. He used a much higher intensity of reciprocation as compared to Gerber and demonstrated that it helped to reduce the process times and improve product quality. They claimed that with the new system a 10-fold reduction in process times could achieved, as compared to conventional static (Walden and Emanuel, 2010). However, they made no attempt to investigate and understand the phenomenon of heat transfer occurring during the process. There is also paucity of scientific literature on the effect of reciprocation on the associated heat transfer, processing efficiency and product quality.

Hence, in order to better understand the reciprocating agitation system and to evaluate the associated heat transfer phenomena in detail, a laboratory scale reciprocating retort was developed by installing a reciprocating mechanism inside an existing conventional static steam retort. The modifications were to allow different frequency and amplitude of reciprocation agitation to cans in a horizontal direction. Once tested, the equipment could subsequently be used for detailed heat transfer evaluations under a range of processing conditions.

2. Materials and methods

2.1. Development of the reciprocating retort

A vertical static steam retort (Loveless Manufacturing Co., Tulsa, OK) located at the pilot plant of Macdonald Campus of McGill University, Ste Anne de Bellevue, Quebec was modified in this study. The retort (E) has an internal diameter of 62 cm, wall thickness of 1 cm, and a depth of 100 cm. This retort had inlets for both steam and air – mixed outside the retort and introduced at the bottom when used as steam/air mixture – to be used as an operating medium. Using steam to heat water in the retort, it could also be used as a water immersion retort. In this study, we used steam as the operating medium. The flow of steam was pneumatically controlled using a PID controller (Control & Readout Ltd., Worthing, Susex, England) to maintain specific temperature and pressure inside the retort. The maximum allowable pressure inside the retort was 308.167 kPa which corresponded to the maximum operating temperature of around 134.44 °C. The come up time of the retort was around 3–4 min, depending on the number of cans in the retort and the operating temperature. This retort was modified to include a reciprocating mechanism for achieving reciprocation container agitation inside the retort. The modification mechanism consisted of a reciprocating cage, a slider-crank assembly and a permanent magnet motor.

2.1.1. Reciprocating cage assembly

The schematic of the modified retort is shown in Fig. 1. The existing static retort (E) was retrofitted to include a reciprocating cage assembly comprising of a cage (A) reciprocating on horizontal rails (B), by the aid of slip rings (C), as shown in Fig. 1c. The steel rails (B) were welded to the interior of the steam retort (E). The slip rings (C) were made from Nylon material. The cage (A) width was 12 cm, length 35 cm and height 17 cm and was designed to hold one level of 4 cans (No. 2) along the diameter of the retort, 2 cans on each side of the axis of reciprocation for balancing. The cans could be placed in three orientations viz. (i) vertically perpendicular, (ii) horizontally parallel, or (iii) horizontally perpendicular to the axis of reciprocation. Metallic can holders were provided to securely hold the cans in position during reciprocation. The cage (A) was connected to a reciprocating rod (D) of 65 cm in length and 2 cm diameter. The rod was inserted into the retort by drilling a hole at one-third height from the top of the retort. Any loss of steam through the hole was minimized by using a properly greased reciprocating seal (F).

2.1.2. Slider crank assembly

The slider crank assembly consisted of an 18 cm diameter stainless steel rotating shaft (H) and a 40 cm length crank (G). The crank (G) could be attached to different positions through pivots along the radius of the rotating shaft (H). Different positions of the pivot provided the possibility of varying the amplitude of reciprocation. The other end of the crank (G) was connected to the reciprocating rod (D) and was constricted to move in a straight line. On rotation of the shaft, the pivoted end of the crank moved in a circular motion of the required diameter, depending on the position of the pivot. The constricted end of the crank, on the other hand, moved in a linear sliding motion. Thus, through the rotation of the shaft, reciprocating motion was created and was transferred to the reciprocating cage (A) through the reciprocating rod (D). The position of the pivot connecting the rotating end of the crank to the shaft, determined the amplitude of the reciprocation provided by the slider-crank mechanism. 15 pivots were drilled along the radius of the rotating shaft at distances from 1.5 to 15 cm from the center of the shaft. Thus, the amplitude of reciprocation ranging from 3 to 30 cm could be achieved through this mechanism.

2.1.3. Permanent magnet motor

The rotating shaft was powered through a ½ HP direct current magnetic motor (*M*) which was connected to the mains through a voltage controller (*I*). The speed of rotation of the motor was controlled by adjusting the input to the voltage controller. For each rotation of the rotating shaft, one cycle of reciprocation was completed by the reciprocation cage. Thus, the voltage controller (*I*) was used to control the reciprocation frequency. The rotation speed of the shaft was monitored through a hand-held non-contact photo tachometer and thus the frequency of reciprocations could be determined. The entire set up was rated for a maximum reciprocation frequency of 5 Hz.

2.2. Simulated food heating model

Instead of using a real food, a simulating food heating model was chosen to conduct thermal studies for the evaluation of developed reciprocating mechanism. Real foods are difficult to work with especially for performance testing of equipment because of the uncertainties in size, stability, thermo-physical properties etc. With simulated inert particles like Nylon, the fabricated particles could be used repeatedly which is not possible with real foods. Further, a Newtonian fluid was used as covering liquid in order to simplify the heat transfer model by removing the changes in viscosity due to the applied stress. Glycerin (Fisher Scientific, Montreal, PQ) at 80% (v/v) concentration was used as the model fluid to simulate a medium viscosity Newtonian fluid. Nylon spherical particles 19 mm in diameter were used to simulate food particulates as their heating behavior lie in the range of common food materials. As food models, Nylon and glycerin combinations have been used earlier in a number of studies and their thermal properties have been summarized in Table 1 (Sablani and Ramaswamy, 1996; Dwivedi and Ramaswamy, 2010b).