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Alternative venting in steam retorts—An approach to energy savings in thermal processing

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ABSTRACT

The venting operation in retorts operating under steam pressure is an important step in the sterilization process and it aims to steam flush the air from inside the equipment in order to ensure sterilization safety. This part of the process is short in time but intensive in steam consumption, and hence this study evaluated an alternative venting operation based on the use of water to displace the air, aimed at reducing this energy consumption. The objective was to evaluate the energy consumption in a steam retort loaded with thermally convective and conductive products, comparing the conventional and alternative venting processes. The steam flow rates showed that the alternative venting process reduced steam consumption by up to 50% as compared to conventional venting.

1. Introduction

Retorts working under steam pressure are the oldest designs and are still the most used by canneries for food packed in metallic containers. For perfect functioning it is necessary to use pure steam, free from air, as the heating medium [1].

The total removal of air from a retort is carried out by injecting steam in at one end and flushing the air out at the other end, an operation called venting. The elimination of air from a retort is fundamental to maintain the efficiency of the convective surface heat transfer coefficient (h) and thus ensure process efficacy. The value for h decreases 10 times when 6% of air remains mixed with the pure steam [2], and it is estimated that 10% of air by volume can reduce the retort process temperature by 3 °C [3]. Thus a deficient venting process can cause significant under-processing, leading to a loss of commercial sterility and in more severe cases, even to the incidence of botulism [4].

For retorts operating under steam pressure, steam generating capacity must be sized according to peak demand, which occurs at the venting stage. After venting, little energy is required to maintain the process temperature [5,6]. Thus even if the venting is relatively short, large amounts of steam are consumed making this a costly operation for the industrial sector.

The alternative approach aimed at reducing energy consumption was described by Berteli et al. [7] based on the use of water to displace the air. In this study, the performance of the involved process variables was evaluated for an empty retort without load: water temperature for venting; water flow rate during retort filling and emptying; temperature distribution and pressure in the retort.

The main reference for this approach is a report published in the 1980s entitled 'Conservation of Energy in Canning Factories in Taiwan' [8]. The authors studied a more economic process for venting, due to its economic importance to Chinese canned food manufacturers. These researchers used a horizontal retort (diameter of 0.9 m × 1.5 m in length) adapted for venting with water, and they achieved a savings of 29% in total steam consumption as compared to conventional processing.

The proposal for this alternative method consisted of removing all the air from inside the equipment by completely filling it with water prior to venting and then, simultaneously, emptying out the water using a pump together with the inflow of steam on the upper side of the retort.

The use of a pump to withdraw the water is imperative, because the pressure inside the retort is less than the pump NPSH (net pressure suction head), since the water temperature is below 100 °C. This means that the pressure inside the retort is a partial vacuum and is dependent on the water temperature.

Although the reference paper of Wang and Chang [8] concluded that water venting was viable for industrial applications, it has been

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supported by only a few experimental results. Many considerations need answers, such as its repeatability, the influence of the initial product temperature, the venting water temperature and its flow rate, and the retort pressure during the venting process, among other considerations.

The present study aimed at a more detailed evaluation of the water venting process, from a survey of the phenomena and the variables involved in the process. In a previous paper [7], the experiment was carried out in a pilot steam processing retort operating with no load of cans, determining the following variables: [a] water temperature for venting; [b] water flow rate during retort filling and emptying; [c] temperature distribution in the retort and [d] retort pressure. The water venting process was shown to be efficient, based on the agreement between the temperatures read on the mercury in glass thermometer (MIG) and those recorded by thermocouples in the heat distribution test, according to protocols of the Institute for Thermal Processing Specialists [9].

In a second step, the results of which are presented in the present paper, the steam consumption necessary for venting the same pilot steam processing retort, loaded with both thermally conductive and convective products was quantified for both the conventional and water venting processes.

Even though crateless retorts are equipments that are partially filled with hot water, their functioning is distinct from that of the present work. It is important to note that in this case the water acts as a cushion during the loading of the cans, which are fed in from the top. When the retort is full, the vessel is closed and steam admitted through the top. Due to the air existing in the headspace of the equipment, this expands under heating and helps to push the water out through a drain. Once the water cushion has completely drained out, the conventional steam venting cycle continues until the retort pressure equals the saturated steam pressure at the corresponding MIG temperature. At this point the bottom venting valve is closed and the temperature rises to the scheduled value and the sterilization cycle starts [10].

2. Materials and methods

2.1. Retort–pump–tank system

Fig. 1 shows the assemblage and instrumentation of the retort–pump–tank system used to study the venting stage of a vertical steam retort (diameter = 0.61 m and height = 0.95 m). The experiments were carried out in the unit operations experimental plant of the Engineering and Post-Harvesting Group – GEPC – ITAL.

A detailed description of the system is presented in Berteli et al. [7]. A short description of the system is presented below to make understanding easy.

A cylindrical stainless steel storage tank (ST) with a volume of 0.25 m^3 was connected to a water supply [1] and a steam line [5]. The tank temperature was controlled using a direct action temperature control valve (Spirax Sarco, model SB, type 128l) [7] and its temperature sensor [8]. A centrifugal pump (CP), KSB Hydrobloc model C700 (0.75 HP, 3450 rpm), was installed between the retort and the tank and connected to both. The function of the pump was to withdraw the water from the retort and return it to the ST to be used in further venting processes.

A rotameter (Matec Flow, model RP-50-1500-RI) [14] was used to read the water flow rate at the pump discharge during the filling and emptying of the retort at the venting stage.

The temperatures in the retort and the water tank were measured using a 16 channel data acquisition system with the software E – Val TM Ver 2.00 ELLAB A/S, model TM 9616. The pressure inside the retort was monitored by a Bourdon type gage (PI) with a −1 to 5 bar scale (Farmabrás) (4″ Diameter, 0.05 bar Divisions) [26], attached to the niche in the retort, and a pressure transmitter (PT) (0–6 bar absolute) [27] (MBS 33, Danfoss) installed at the same spot.

In order to avoid cavitations during water venting, a pump rotation control was developed to maintain the retort pressure at values above its NPSH. A frequency inverter (Siemens Vector 6SE3221-0CC40), [30] (FI) was connected to the centrifugal pump (CP) and modulated according to the signal read by the (PT) [27]. The inverter control signal was generated by a PLC (HI ZAP 500, HI Tecnologia). A variable set point controller program to regulate the pump rotation via the inverter frequency was coded in Labview 7.1 (NI, 2001) [31].

During the venting process, the steam passed through an orifice plate (OP) [33] via the valves [32A, 32B], the orifice plate being calibrated to operate in the range from 50 to 300 kg/h (Valblock, NX0111). The steam flow rate signal of the pressure transmitter (PT) (Smar, LD301l) [34] was read by an electronic logger (Novus, MyPcLab) [35] connected to a computer [31]. At the end of venting, during the sterilization step, which occurred with a much smaller steam flow, the valves [32A] and [32B] were closed and valves [20A] and [20B] opened to direct the steam through a Vortex type steam flow meter calibrated to operate in the 5–50 kg/h range (OVAL Smart EX DELTA model VXW 1015 N526106A) [21], connected to the second channel of the data logger [35].

During sterilization, the temperature of the retort was controlled by a positioning valve (PV) (Bürket, Positioner 1067) [19] connected to a PT-100 temperature sensor attached to the niche of the retort beside the MIG [29].

2.2. Water venting process

A detailed description of the water venting process in the retort–pump–tank system has been described in Berteli et al. [7]. For the retort filling stage, the water in the tank, at a pre set temperature, was transferred via the centrifugal pump (CP) to the bottom of the retort on opening the valve [16]. Thus the water passed through the three way valve [12] and then through another three way valve [15]. Once water overflow was observed coming out the venting valves and bleeders [28], the bottom of the retort [16] and all the overflow valves were closed and the pump turned off.

During the venting stage, as the water was flowing out at the bottom of the retort, steam was simultaneously entering at the top. To achieve this, the incoming steam valve at the top [22] and the water outlet valve at the bottom of the retort [16] were opened when the pump was switched on. Thus the water passed through one three-way valve [12] positioned in the direction from retort to pump, was then suctioned through the pump, and finally passed through another three-way valve [15] positioned in the direction from pump to storage tank.

Two check valves [11] and [17] were installed to prevent the water from back-flowing.

2.3. Conventional and water venting systems in retort loaded with convective and conductive products

For the venting tests, 150 tuna type cans (d = 83 mm × h = 38 mm with 0.17 mm sheet metal gages) filled with water (convective) or a 5% Bentonite (Volclay SPV, Buntech Tecnologia Insumos) suspension (conductive) [11], with no head space, were closed using a vacuum can seamer (John Heine, model 71D, series 2). The cans were loaded into a basket with the tops upwards, producing seven layers misaligned in a vertical arrangement to prevent can stacking.

To monitor the retort and product penetration temperatures, seven thermocouples (TC) were distributed at different points inside the retort and inside some of the cans. All these TC's were located on the axis of the basket. The thermocouples TC 1, 2, 3 and 4, whose function was to measure the retort temperatures, were

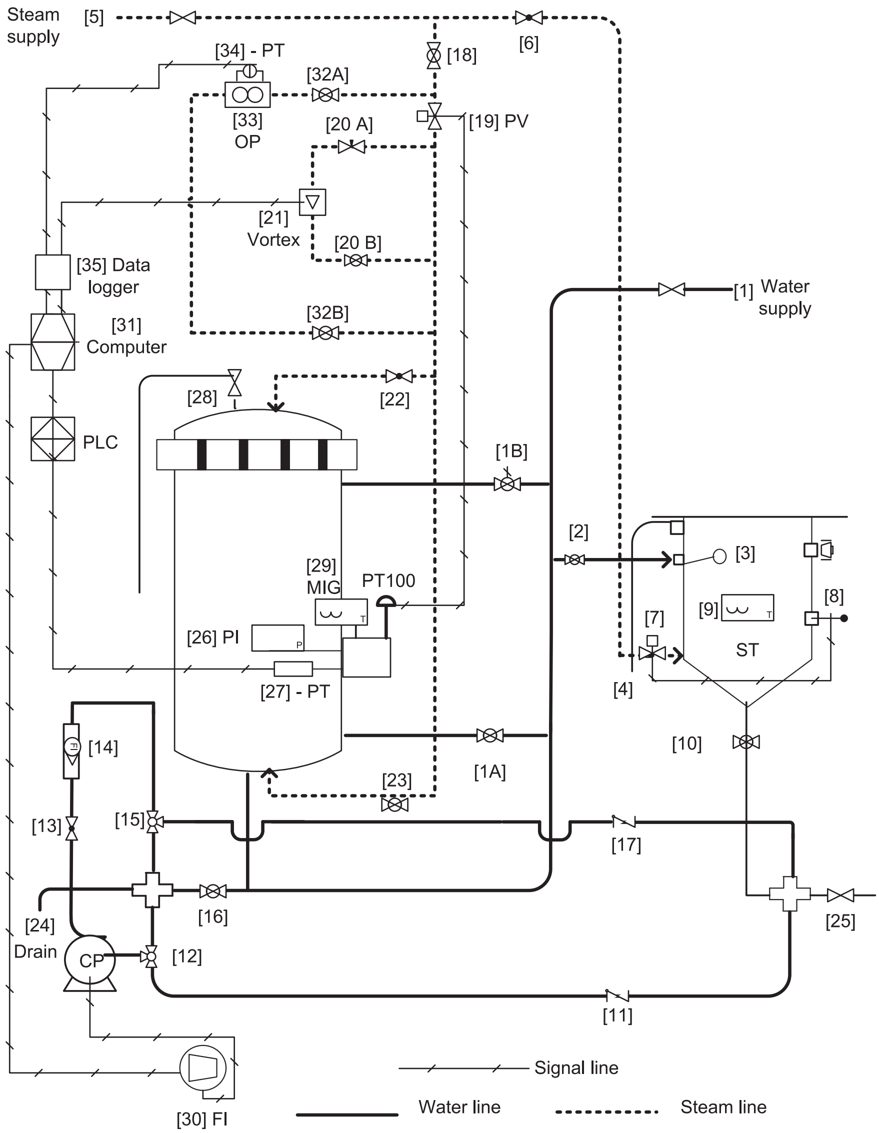

Fig. 1. Schematic of the retort–pump–water tank system: [1] water line (A) bottom part of the retort entrance and (B) upper part of the retort entrance; [2] spherical valve; [3] brass buoy; [4] overflow drain; [5] steam line; [6] spherical valve; [7] direct action temperature adjustment valve; [8] adjustment valve temperature sensor; [9] thermometer; [10] spherical valve; [11] check valve; [12] spherical three way valve; [13] globe valve; [14] rotameter; [15] spherical three way valve; [16] spherical valve; [17] check valve; [18] spherical valve; [19] positioning valve for the temperature control of the retort (PV); [20] needle valve (A) and spherical valve (B); [21] steam flow rate Vortex type meter: [22] spherical valve; [23] spherical valve; [24] retort drain; [25] water tank drain; [26] vacuum pressure gage (PI); [27] pressure transmitter (PT); [28] venting valve and bleeders; [29] MIG; [30] frequency inverter (FI); [31] computer; [32A, 32B] spherical valves; [33] orifice plate (OP); [34] pressure transmitter (PT); [35] data logger.

fitted to the side of cans whose bottom and lid had been removed. These open cans were placed at different positions (top, middle and bottom) of the retort. TC4 was placed below the steam distributor of the retort, represented by the dotted line in Fig. 2. TCs 5, 6 and 7 were placed inside cans filled with water (1/3 height from the bottom) or bentonite suspension (geometric center) encased by protective wells.

The experiments were carried out with a steam pressure of 6 bar in the main supply line, and a retort temperature set point of 121 °C. During the conventional venting stage, the steam entered at the bottom of the retort [23] (Fig. 1), and all the bleeders were kept open as also the venting valves [28] (Fig. 1), until the readings of all the retort thermocouples converged to the same temperature. As from this point, the venting valves were closed so as to reach the set point temperature, and the bleeders remained partially open during the sterilization stage.

During the water venting experiments, the water temperatures studied were: room temperature (around 25 °C), 50 °C and 80 °C.

3. Results and discussion

3.1. Retort–pump–tank system: controlling the withdrawal of the water

In the study carried out in the retort with no load [7] the water venting time required to discharge approximately 0.22 m^3 of water ranged from 2.5 min (venting water at room temperature) to 1.4 min (venting water at 80 °C), with no cavitation in the centrifugal pump, which was run at full frequency (60 Hz). The water inside the retort was heated by the steam coming in through the top. Since hot water has a lower density than cold water, it remained above the mass of water and did not mix with the colder water just below it. This hot water presented a higher vapor pressure and maintained the pressure inside the retort above the NPSH for both situations.

However, in the preliminary tests with the retort loaded with product to its maximum capacity, venting was not possible, due to cavitation of the pump when running at 60 Hz. When the water

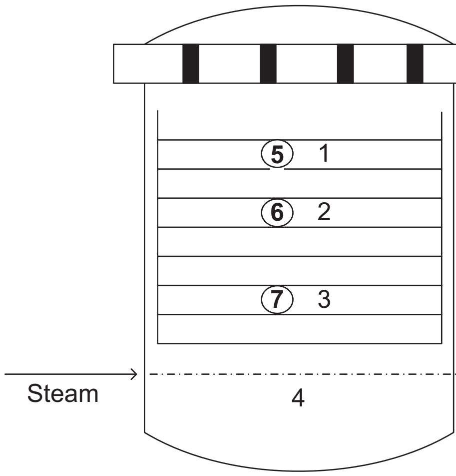

Fig. 2. Distribution of the thermocouples inside the retort.

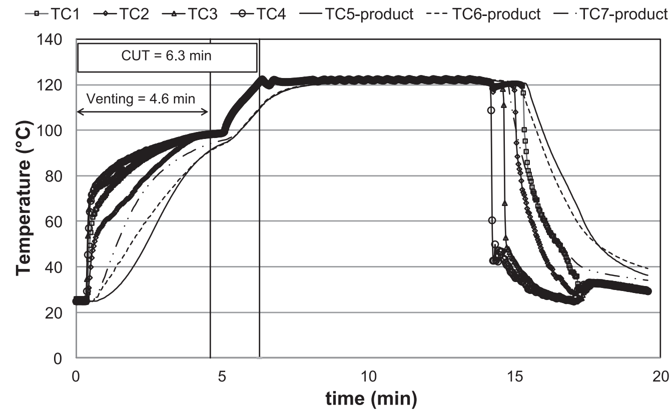

Fig. 3. Evolution of the temperature histories for the sterilization process: conventional venting, convective test (1CConv).

venting system was run with a loaded retort, the incoming steam was consumed in heating up the water plus the load of cans being exposed to the steam, when the water level was lowering due to emptying. As a result, the temperature in the headspace of the retort was not so high, and as a consequence, the net pressure inside the retort was below the minimum NPSH necessary to pump the water out, resulting in the appearance of cavitation.

In order to avoid pump cavitation, a study was carried out to determine the best operation of the frequency inverter controlling the centrifugal pump speed [30 and 31] (Fig. 1).

Considering that it is the pressure in the retort that governs the water venting system, a real time variable set point control was coded in the LabView 7.0, grounded on the retort pressure.

Based on the preliminary tests, Table 1 shows the variable set point control for the inverter frequency values as a function of retort pressure (PT) [27] (Fig. 1).

The experiments using the conventional and water venting processes were carried out in the retort–pump–tank system using thermally convective and conductive products. The steam flow rate, water flow rate, pressure and temperature of the retort and the product were monitored during the experiments.

3.2. Conventional and WVS processes in the retort loaded with thermally conductive and thermally convective products

3.2.1. Thermally convective product

3.2.1.1. Conventional venting process. The 1CConv test refers to the conventional venting process in the retort loaded with thermally convective product. Fig. 3 shows the temperature histories of the sterilization process. As the process began, the temperature evolved quickest in the product positioned at the bottom of the retort [TC7], followed by that in the center [TC6], the slowest being that at the top of the retort. The rises in retort temperature were TC 4, 3, 1 and 2, respectively. The venting time, when all the thermocouples converged to the same temperature, was 4.6 min and the CUT was 6.3 min.

Fig. 4A shows the temperature histories for the 1CConv test during CUT (venting and temperature rise) and Fig. 4B shows the steam flow (SF) during CUT in the conventional venting process.

Integration of the steam flow vs. time curve ($\Sigma SF \times \Delta t$) in Fig. 4B yields the amount of steam consumed in each stage (Table 2). In the processing phase, the amount of steam consumed depends not only on the duration of the process but also on the kind of product being processed.

3.2.1.2. Alternative venting process. During the water venting experiments, the water temperatures studied were: room temperature (around 25 °C), 50 °C and 80 °C. Only the Figures corresponding

Table 1
Values obtained for the variable set point control.

Pressure (bar)		Pump rotation (%)	Frequency – inverter (Hz)
T_{water} = 50 and 80 °C	T_{water} = room		
0–0.85	0–0.90	20	12
0.86–0.99	0.91–1.10	42	25
1.00–1.15	1.11–1.20	75	45
Over 1.15	Over 1.20	100	60

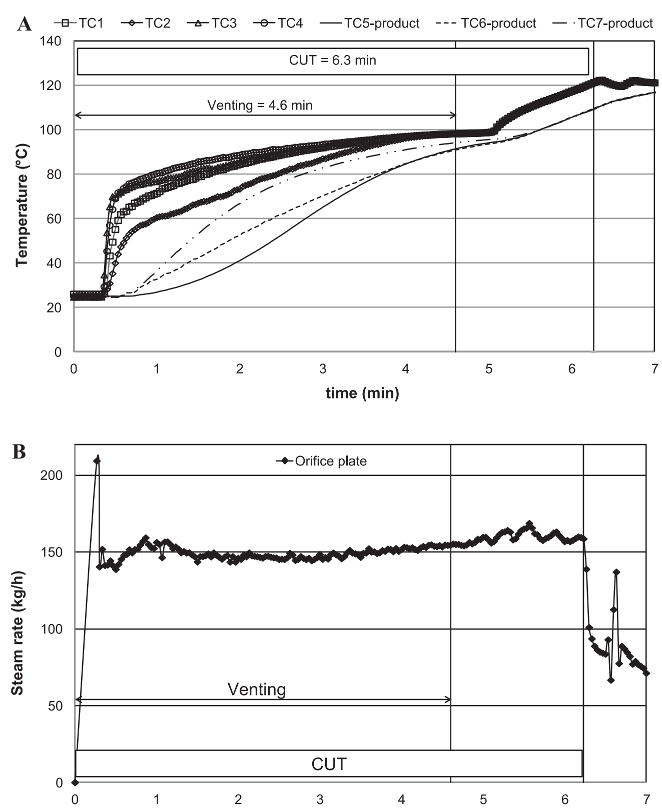

Fig. 4. Evolution of the temperature histories – CUT (4A) and evolution of the steam flow – CUT (4B): conventional venting process, convective test (1CConv).

Table 2
Venting times and steam consumption for each stage of the sterilization process.

Test	Temp. water (°C)	Venting time (min)	Steam consumption				
			Venting (kg)	CUT (kg)	Process (kg)	Tank (kg)	Steam savings during venting
Convective product							
1CConv	–	4.6	10.9	15.3	3.8	–	–
2CConv	–	4.1	9.6	13.9	2.9	–	–
1AConv	Room	6.4	10.0	12.8	1.4	–	–
2AConv	Room	5.7	11.7	15.2	2.2	–	–
3AConv	50	4.5	8.1	11.1	2.3	15	15–25%
4AConv	50	4.6	8.6	12.0	1.6	15	10–21%
5AConv	80	2.6	5.0	8.4	2.8	30	47–54%
6AConv	80	2.9	5.2	8.5	2.8	30	45–52%
Conductive product							
1CCond	–	3.7	8.5	12.6	14.1	–	–
2CCond	–	3.8	8.8	13.2	14.2	–	–
1ACond	Room	5.9	9.3	11.5	9.2	–	–
2ACond	Room	5.8	11.9	14.4	13.0	–	–
3ACond	50	3.5	6.6	9.9	18.9	15	22–25%
4ACond	50	3.8	6.7	10.1	14.1	15	21–23%
5ACond	80	2.4	4.0	6.3	8.5	30	52–54%
6ACond	80	2.4	5.0	7.9	11.1	30	41–43%

to water venting at 80 °C were presented and the main results for all the convective tests are shown in Table 2.

In the conventional process, CUT was defined as the sum of the venting time in the retort plus the pressurization time required to reach the process temperature. In the water venting process, CUT was defined as the time from the start of steam injection up to the end of the emptying time (considered as venting) plus the pressurization time required to raise the temperature. Table 2 presents the results for all the venting tests.

The water venting time at 50 °C was shorter than that at room temperature (Tests 3AConv, 4AConv and Tests 1AConv, 2AConv respectively, Table 2), due to the increase in the water vapor pressure, and was similar to that of the conventional venting time (Tests 1CConv and 2CConv, Table 2).

Figs. 5 and 6 show the results obtained for water venting at 80 °C for the convective process, Test 5AConv. The rise in retort temperature (Fig. 5) was the inverse of that observed in the conventional process, since the steam entered the upper part of the retort. The sequence of rises in the retort temperature was TC 1, 2, 3 and 4 and TC 5, 6 and 7 for the product. Notice that the slopes of the curves for the products changed when the heating medium changed from water to steam, due to the change in the heat transfer coefficient (Fig. 5).

Fig. 6A shows the venting time (2.6 min) and the CUT time (4.1 min). The steam consumption values calculated from the

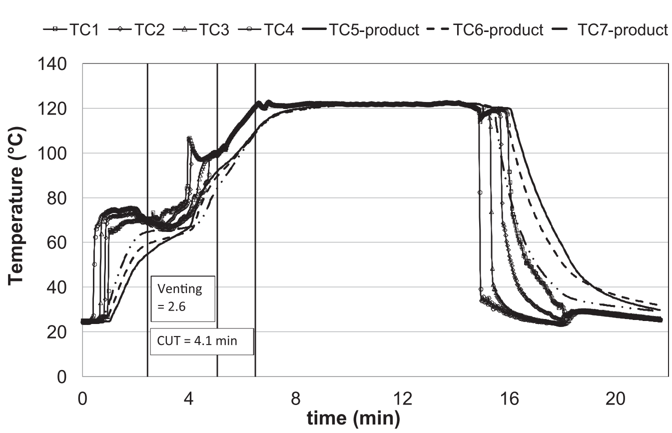

Fig. 5. Evolution of the temperature histories for the sterilization process: water venting, $T = 80$ °C, convective test (5AConv).

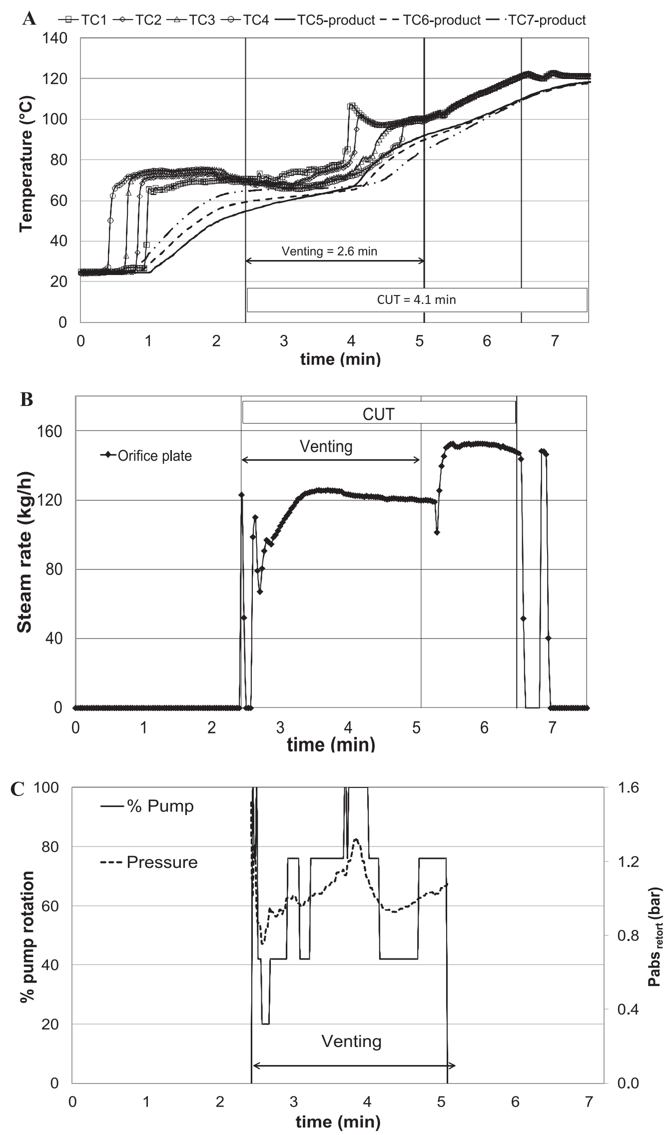

Fig. 6. Evolution of the temperature histories – CUT (6A); evolution of the steam flow – CUT (6B) and history of the pump rotation and retort pressure during the venting stage (6C): water venting, $T = 80$ °C, convective test (5AConv).

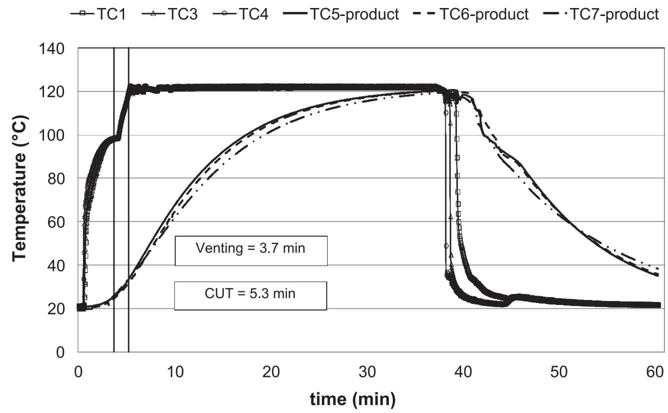

Fig. 7. Evolution of the temperature histories for the sterilization process: conventional venting, conductive test (1CCond).

integration of the area under the curve in Fig. 6B were 8.4 kg during CUT, of which 5.0 kg were used in the venting process and 3.4 kg in the temperature rise (Table 2). The pump rotation history during the venting stage and the retort pressure obtained in the Test 5AConv are shown in Fig. 6C. A more efficient performance for pump rotation, expressed as a shorter venting time, was observed for the tests at lower temperatures, due to the higher water vapor pressure at (80 °C) (Table 2).

The results obtained for Test 6AConv, the repetition of Test 5AConv, are shown in Table 2.

3.2.2. Thermally conductive product

3.2.2.1. Conventional process. During the conductive tests, sterilization was stopped and cooling started when the product temperature indicated by TCs 5, 6 and 7 reached values near 121 °C.

Test 1CCond corresponds to the conventional venting of a retort loaded with conductive product (Fig. 7).

The venting time in the conventional conductive process (1CConv) was shorter (3.7 min) than that in the convective process (4.6 min) (Table 2). This is due to the fact that, under the same conditions, convective products heat up faster than conductive ones. Considering this, convective products act as a heat sink such that the whole product volume exposed to the steam must reach temperatures near to 100 °C in order to generate a pressure inside the retort above the NPSH. For conductive products, due to their slower heating characteristics, only a small volume near the container surface must reach this temperature level, leading to a faster rise in retort pressure to surpass the required minimum NPSH.

Fig. 8A presents the CUT temperature history for test 1CCond and Fig. 8B the steam flow (SF) during CUT for the conventional venting process.

3.2.2.2. Alternative venting process. During experiments with the water venting of conductive products, the water temperatures studied were: room temperature (around 25 °C), 50 °C and 80 °C. Thus only the Figures corresponding to water venting at 80 °C were presented. The main results for all the conductive tests are shown in Table 2.

Test 5ACond corresponds to the alternative water venting test at 80 °C for the conductive process. The venting time in the Test 5ACond was 2.4 min and 3.5 min for CUT (Fig. 9A). The steam consumption values (Fig. 9B) were 6.3 kg during CUT, of which, 4.0 kg were used in the venting process and 2.3 kg in the temperature rise (Table 2). The pump rotation history during the venting stage and the retort pressure obtained in Test 5 ACond are shown in Fig. 9C.

According to Table 2, at 50 and 80 °C CUT demands less steam with water venting than with conventional systems. The column

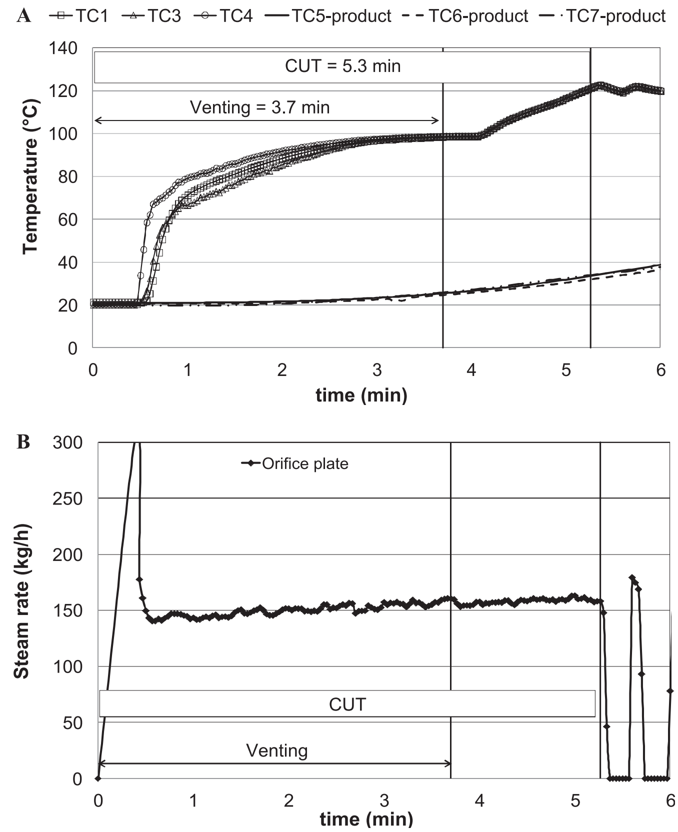

Fig. 8. Evolution of the temperature histories – CUT (8A) and evolution of the steam flow – CUT (8B): conventional venting process, conductive test (1CCond).

entitled “Steam savings during venting (%)” shows there was a percentage reduction of 10–25% with the alternative process at 50 °C and of 41–54% at 80 °C as compared the steam consumption during the conventional venting process.

The steam consumption required to heat the water storage tank should also be taken into account. The column “Steam Consumption Tank” in Table 2 shows the mass of steam required to heat the water (250 l) to 50 and 80 °C, calculated from the measurement of the volume of tank water before and after steam injection. The results were confirmed by an energy balance.

However, the water used in the venting stage is still clean, and is therefore returned to the tank for reuse in other processes, either in the same retort or in other equipment. Thus the water is only heated once to the desired temperature and from then on only to maintain its temperature.

In the alternative venting process 30 kg of steam was required to heat the water in the tank from 25 to 80 °C. According to the steam consumption presented in Table 2, CUT uses about 15 kg of steam in the conventional venting process as against 8.5 kg in the water venting process at 80 °C, representing a saving of 6.5 kg of steam or 45%. Thus the mass of steam used to heat the water in the tank is recovered after less than 5 cycles of sterilization in the water venting process at 80 °C.

Based on the industrial scenario, the number of sterilization cycles in a processing plant can vary from 30 to 240 cycles a day, depending on the retorts existing and/or the duration of the sterilization process. The steam consumption required to heat up the water in the tank is very small considering all the economy obtained from the alternative venting stage.

The use of heated water in the alternative venting is also important for the energetic efficiency of the process, because the products to be sterilized, with few exceptions, are hot filled (70–80 °C) prior

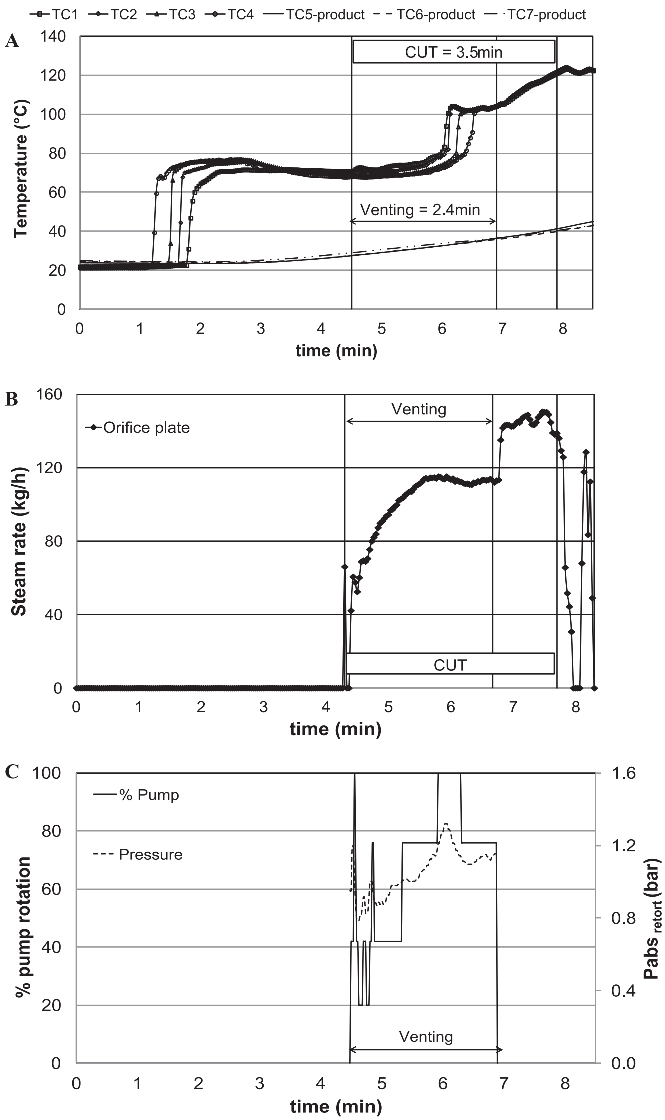

Fig. 9. Evolution of the temperature histories – CUT (9A); evolution of the steam flow – CUT (9B) and history of the pump rotation and retort pressure during the venting stage (9C): water venting, $T = 80\,^{\circ}\mathrm{C}$, conductive test (5ACond).

to sterilization. This fact, associated with the hot water used for venting in this alternative process, presents an interesting approach for the reduction of energy use in canneries, along with important environmental impact aspects.

4. Conclusion

The venting water method is advantageous to reduce steam energy consumption during the venting process in retorts operating under steam pressure.

The pressure inside the retort varied according to the water venting temperature. For adequate venting the pump rotation had to be controlled as a function of the retort pressure.

The water venting process at 80 °C showed an economy of about 50% in the total steam consumption as compared to the conventional venting process.

A second important issue was that the boiler could be operated in a more uniform way, with a reduction in the peak steam demand observed in the conventional venting process.

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