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The analysis of an alternative approach to the venting process in retorts operating under steam pressure

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ABSTRACT

The operation named venting is a step in the sterilization process in retorts using steam pressure. It is intended to remove all air from the inside of the equipment by injecting steam. Although only for a short period of time, great quantities of steam are used, making venting an expensive operation. This study aimed to evaluate an alternative to the venting process with a reduction in steam energy expenditure. A system was adapted and instrumented, which allowed for the study of the phenomenon of venting using water for the air displacement. The alternative methodology proposed was shown to be promising and efficient for an empty retort with no load. The efficiency at this stage of the study was based on evaluating the differences in the temperature readings using a glass mercury thermometer and the temperatures recorded by thermocouples distributed within the retort.

1. Introduction

Equipment operating using total water immersion, cascade, spray or an air/steam mixture are emerging on the market with the aim of processing semi-rigid flexible packages and/or reducing steam energy consumption. However, retorts working under steam pressure are of an earlier design, and are still mostly used by the food processing industries when the food is packed in metallic recipients.

For perfect functioning it is necessary to use pure steam, (exempt from air) as a means of heating (Food Processors Institute, 1990). This condition is obtained by means of an operation named venting, intended to totally remove the air from the inside of the equipment by injecting steam.

The removal of air from the retort occurs by injecting steam at one end and removing the air at the other end. The elimination of air from the retort is fundamental to assure uniformity and efficiency of the sterilization, since the presence of regions with stagnant air act as a thermal insulator, decreasing the efficiency of the heat transference process (Lund, 1975), resulting in sub processing. Even though the outflow of steam demanded at this stage is of short duration, it makes up 25–50% of the total steam consumed during the whole thermal processing (Lopez, 1981). Furthermore, the condition becomes worse in installations using many retorts, where two or more units may be in the venting cycle at the same time, resulting in a great demand on steam production (Lopez, 1981).

Complete venting has to be established in a heat distribution test in which several temperature sensors are distributed on the inside of a retort loaded to its maximum capacity, all converging to the same temperature (May, 2004).

After venting, the following steps are: a temperature rise in the retort until it reaches the processing temperature by pressurizing the equipment with steam (the ventilation time plus the temperature rise time is called the "come-up-time" – CUT), sterilization and cool off.

The history of the increasing costs of a barrel of crude oil, the limitations of other fuel sources and also the great problem of the environmental impact of polluting gas emissions, are the reasons that drive and justify the study of the feasibility of an alternative methodology for the venting process. Various studies on energy consumption, conservation and recovery were carried out during the 70s and 80s so as to optimize the usage of steam (Lopez, 1981; Bhowmik et al., 1985; Rao et al., 1986; Del Valle and Soule, 1987a,b). Most of these papers are examples of theoretical and experimental evaluations of the operational modeling of venting, and of the theoretical evaluation and practice of the consumption of energy by retorts using steam pressure. For practical reasons considering the existing installations, all the papers dealt with the optimization of venting in the traditional way.

The alternative approach described in this paper is based on the use of water to displace the air, in place of the conventional venting process used in retorts operated under steam pressure.

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The main reference for this approach is a paper published in the 80s (Wang and Chang, 1982). These researchers used a horizontal retort (diameter of 0.9 × 1.5 m long) adapted for venting with water, and they concluded that they economized 29% of the total steam consumption as compared to conventional processing.

This reference was a technical report showing few experimental results, leaving many considerations and questions on the process without answers, such as its repeatability, the influence of the initial product temperature, the influence of the venting water flow rate and temperature, amongst other important considerations regarding the venting efficiency using the proposed alternative.

Crateless retorts are equipments that are initially filled partially with hot water, which acts as a cushion for the cans, which are fed in from the top. When the retort is full, the vessel is closed and steam is admitted through the top. Due to the air existing inside the equipment, this expands and helps to push out the water through a drainpipe. Once the cushion of water has completely drained out, the conventional steam venting cycle continues until the retort pressure equals the saturated steam pressure at the corresponding mercury thermometer temperature. At this point the bottom venting valve is closed and the temperature rises to the scheduled value and the sterilization cycle starts (Berk, 2009).

The present research aimed to study an alternative venting operation carried out with the use of water, and evaluate the performance of the variables involved in this process.

Thus [1] a vertical pilot steam processing retort and a venting processing unit using water were set up. During the alternative venting process [2], the water temperature for venting, the water flow rate during retort filling and emptying, the temperature distribution and the pressure within the retort were studied.

2. Material and methods

2.1. Setting up of the Retort–Pump–Tank

A vertical steam retort was used with a diameter of 0.61 m, height of 0.84 m and a 0.11 m high bowing of the covers as existing in the experimental plant of the unit operations of the Engineering and Post-harvesting Group – GEPC – ITAL.

The venting water was stored in a vessel consisting of a cylindrical stainless steel (430) body with a conical bottom, an opening for incoming steam, a crosspiece of perforated tubes, an opening for the incoming water and temperature sensors. The tank temperature was controlled using a direct action temperature control valve, calibrated to operate in the range from −20 °C to 110 °C (Spirax Sarco, model B, type 128, Brazil).

A centrifugal pump (KSB Hydrobloc model C700, Brazil) with an open rotor with a brass casing and a mechanical seal for temperatures of up to 90 °C was connected to the retort and to the tank. The function of the pump was to help withdraw the water from the retort and also allow for the reuse of the water in other venting processes.

A rotameter (Matec Flow, model RP-50-1500-RI, Brazil), calibrated from 1 m^3/h to 10 m^3/h with divisions of 0.2 m^3/h, 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 water tank were measured using a 16 channel data acquisition system and software E – Val TM Ver 2.00 ELLAB A/S model TM 9616 Roedovre, Denmark), and the needle type thermocouples (Ellab SSA TS, Denmark) were calibrated against an ASTM thermometer.

The pressure inside the retort was monitored using a vacuum pressure gage and a pressure transmitter (MBS 33, Danfoss, Denmark). The transmitter signal was fed to an electronic data acquisition system (MyPcLab module – Novus, Brazil) connected to a computer by means of software allowing for recording of the pressure readings.

It is fundamental that all the interconnections are properly sealed off to avoid the purged air returning to the retort. Thus Loctite 1114 was applied to all the connections, valves and bleeders at the steam entrance and in the water and compressed air lines (the latter used during the cooling off stage of the retort) making up the Retort–Pump–Tank System.

Fig. 1 shows the set up and instrumented system described above. The water storage tank is connected to the utility water line [1] by means of a valve [2] and its water level maintained stable by a brass overflow control valve [3]. In the case of an excess of water in the tank, the water leaves the tank through an overflow device [4]. The tank is also connected to a steam line [5] to heat the venting water through the valve [6]. The water temperature is controlled by means of a direct action valve [7] activated by a thermostat [8] and monitored by a bimetallic thermometer, graduated from 0 °C to 120 °C with 2 °C divisions (Instrucamp, Brazil) and located half way up the tank.

As for the filling stage of the retort (Fig. 1A), the water in the tank, set at the pre-determined temperature, is aspired through the centrifugal pump after being directed through a three way valve [12]. The flow rate can be controlled by means of a globe valve at the discharge of the pump [13] and is read by a rotameter [14]. The water passes through another three way valve [15] and the flow is directed to enter the lower part of the retort on opening the valve [16]. When the overflow can be observed through the venting valves and bleeders [28] (Fig. 1), the incoming retort valve [16] is closed, and all the overflow valves and the pump turned off.

During the venting stage, as the water is flowing out from the bottom of the retort, so steam is entering at the same time at the opposite end. To achieve this, the incoming steam valve on the upper part of the retort [22] and the water outlet valve of the retort [16] are opened, and the pump is restarted. To empty the retort, Fig. 1B, the water passes through the three-way valve [12], positioned in the direction from retort to pump. The water is aspired through the pump passing through the rotameter and the three-way valve [15], also positioned in the direction from pump to storage tank. To avoid the water returning, two retention valves [11] and [17] were installed. In the case of a steam flow check in subsequent studies, the needle valves can be opened [20A] for better flow adjustment, and the sphere valve used to read the Vortex type steam flow meter (OVAL Smart EX DELTA, model VXW 1015 N52610A, Japan) can be connected to a data recorder. At the end of venting, the pump is turned off and the retort drain opened to drain off any residual water. After draining off all the water from the retort, the drain is closed, the bleeders (Fig. 1) are partially opened and the sterilization stage begins. During sterilization the temperature of the retort is adjusted by a positioning valve (Bürket, Positioner 1067, Germany) [19] connected to a PT-100 temperature sensor attached to the housing of the retort beside the mercury thermometer [29]. The pressure in the retort is read on a Bourdon type vacuum gage with a scale from −1 bar to 5 bar and divisions of 0.05 bar (Farmabras, Brazil) [26], also attached to the housing of the retort. A pressure transmitter (Danfoss, MBS 33, Denmark) [27] was installed at the same place, connected to a data recorder to acquire the data on the pressure in the retort.

2.2. Study of water venting from a retort with no load, operated under steam pressure

This study was carried out so as to adjust the Retort–Tank–Pump system, in order to survey and study the processing variables and check out the occurrence or otherwise of retort venting using the proposed methodology, by means of heat distribution tests.

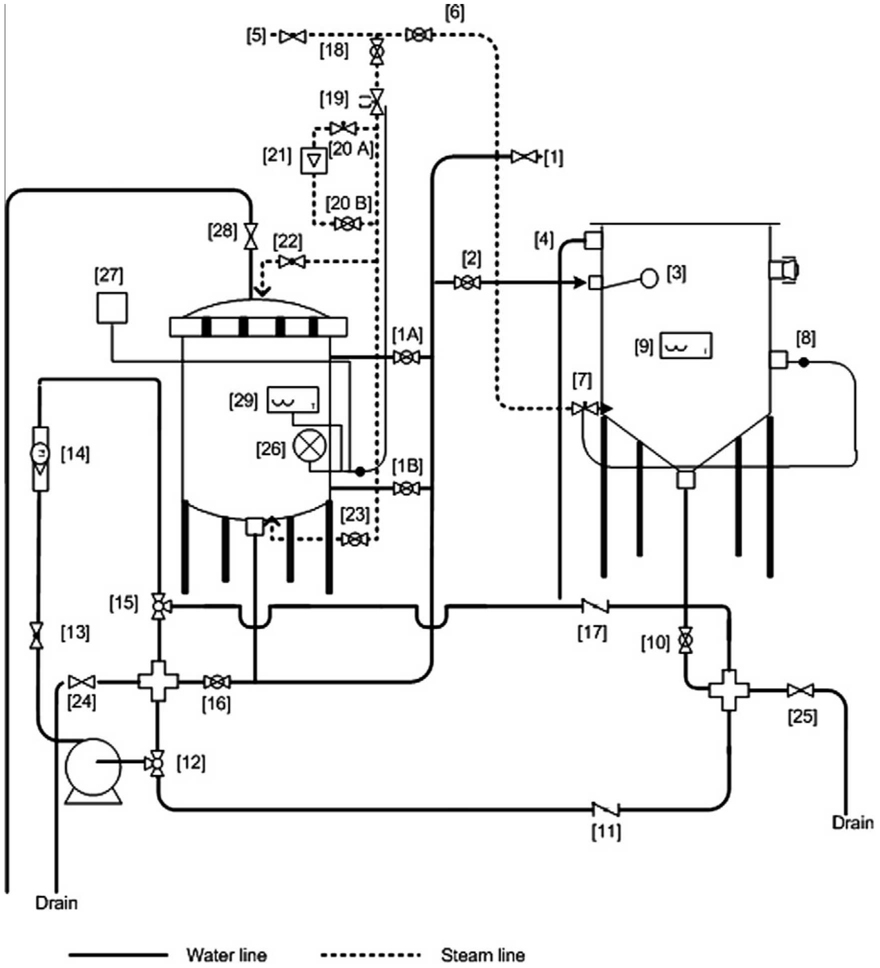

Fig. 1. Outline of the Retort–Pump–Water Tank System: [1] water line (A) upper part of the retort entrance and (B) bottom part of the retort entrance; [2] sphere valve; [3] brass buoy; [4] overflow drain; [5] steam line; [6] sphere valve; [7] direct action temperature adjustment valve; [8] adjustment valve temperature sensor; [9] thermometer; [10] sphere valve; [11] retaining valve; [12] three way valve; [13] globe valve; [14] rotameter; [15] three way valve; [16] sphere valve; [17] retaining valve; [18] sphere valve; [19] positioning valve for the temperature adjustment of the retort; [20] needle valve (A) and sphere valve (B); [21] steam flow rate Vortex type meter: [22] sphere valve; [23] sphere valve; [24] retort drain; [25] water tank drain; [26] vacuum pressure gage; [27] pressure transmitter; [28] venting valve and bleeders; [29] thermometer.

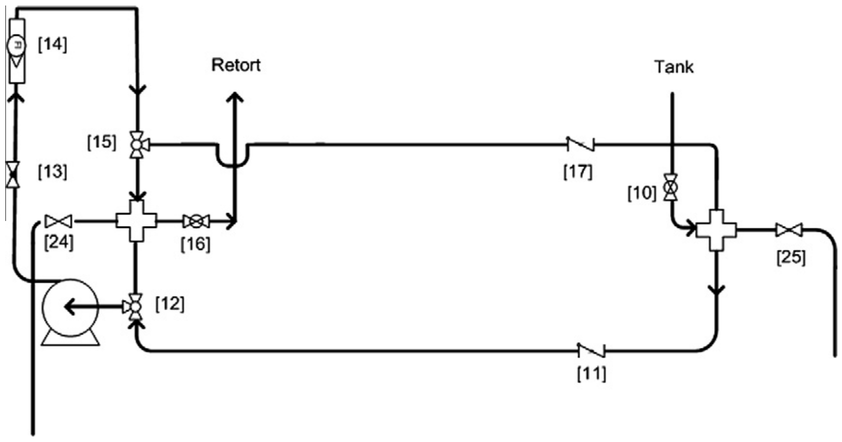

Fig. 1a. Outline of the retort filling stage.

The venting experiments from the retort with no load were carried out using venting water at five different temperatures (from room temperature to 80 °C), a pressure gauge in the steam line at 3 bar and a retort temperature set point of 121 °C.

To determine the initial temperature of the retort and the processing variables, a few experiments were designed with the equipment first cold and then repeated with it still hot.

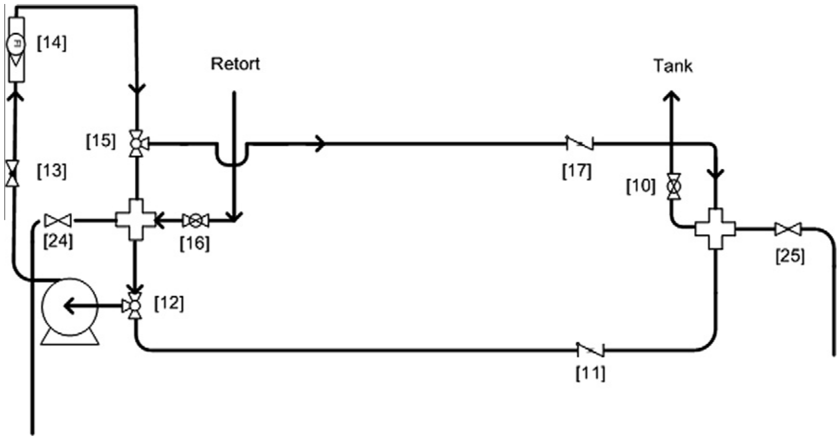

Fig. 1b. Outline of the emptying step of the retort.

During the venting stage, the following variables were evaluated: water temperature, retort filling and emptying flow rates, retort pressure and the temperature distribution inside the retort. The items below describe the methodology used for each of the variables.

2.2.1. Venting water temperature

The water temperature is an important item to be set, since it directly influences the thermal efficiency of the venting process. It must be higher than the initial temperature of the product, except in some special cases, to avoid the product from cooling off. Therefore, the maximum possible temperature of the venting water was studied for an efficient air removal from the retort, without causing cavitation in the water removal centrifugal pump.

In all the venting experiences, two needle type thermocouples (Ellab) were maintained inside the water tank to read the water temperature.

The water temperatures studied were: room temperature (around 25 °C), 50 °C, 60 °C, 70 °C and 80 °C.

2.2.2. Venting water flow rate

The venting water flow rate is highly crucial to the process, since it interferes in the venting time. The flow rates corresponding to the previous items were registered during the filling and emptying of the retort in the venting process.

To record the flow rate values, a photographic camera was installed in front of the rotameter and a movie shot before venting was started. From the movie, the flow rate values were read every 20 or 10 s, depending on the total time taken to fill or empty the retort.

2.2.3. Retort temperature distribution

To register the retort temperatures during venting under the various operating conditions, six thermocouples (TC) (Ellab) were fastened onto wires and distributed at different points within the retort as indicated in Fig. 2. The heights of thermocouples 1, 2, 3, 4, 5 and 6 with respect to the bottom of the retort were, respectively 63, 50, 40, 31 and 10 cm. TC 6 was placed below the steam distributor of the retort, represented by the dotted line in Fig. 2.

TCs 3 and 6 were placed on the vertical axis of the cylinder and TCs 1, 2, 4 and 5 at about 0.15 m (half of the retort diameter) from the vertical axis. TC 5 was placed near the housing where the mercury thermometer was installed.

After the retort reached its stable operating condition, the temperature shown on the mercury thermometer was recorded at pre-set time intervals. The values of the temperature read on the mercury thermometer were compared with the values of the temperatures recorded by the thermocouples. According to the protocols of the Institute for Thermal Processing Specialists (2004), to ensure that the retort has been vented, the difference in the readings of the thermocouples cannot vary more than ±0.3 °C as compared to the mercury thermometer. Complete venting is determined using temperature distribution tests with the retort loaded to its maximum capacity. However, the present study was of an investigative nature, aimed at making the necessary adjustments to the system, and hence the temperature distribution was determined with the retort empty.

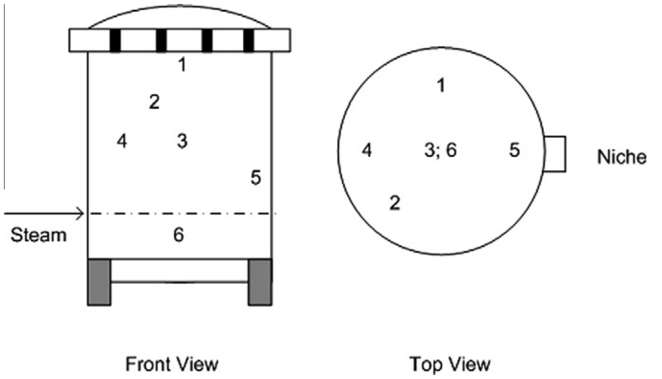

Fig. 2. Distribution of the thermocouples: retort with no load and venting using water.

2.2.4. Retort pressure distribution

The pressure inside the retort was monitored on-line during venting using the MyPcLab Novus electronic recorder. The pressure measurements were obtained from the retort niche near the mercury thermometer. The pressure could also be followed using the vacuum gage placed near the housing of the retort.

3. Results and discussion

3.1. Study of venting using water in the retort with no load

3.1.1. Venting water temperature and flow rate

Venting was carried out using the methodology described in Section 2.2.

To better elucidate the results of venting as a function of the water temperature, the results will be presented in conjunction with the description of the filling and emptying flow rates, since they are directly related to each other.

- Filling
  Independent of the water and equipment temperatures, in all experiments the retort filling flow rate was from 8 to 8.5 m^3/h and the total filling time was 2 min.
- Emptying
  The emptying flow rate of the water varied according to its temperature and depended on the equipment being hot or cold.

Fig. 3 shows the evolution of the emptying flow rate during the venting of the retort with the water and equipment at room temperature. In Tests 1 and 3 the retort was cold, and in Tests 2 and 4 it was hot. The average flow rate in Test 1 was 5.3 m^3/h and the emptying time 2.5 min. The results for Tests 1–4 are presented in Table 1. The average flow rate was calculated without including the last step of the experiments, since it corresponded to the end of the emptying stage, that is, with a value of 0 m^3/h. Fig. 3 shows that the flow rates increased throughout the emptying stage procedure.

In the tests with the venting water at 50 °C, the flow rates were greater when the equipment was hot.

Fig. 4 compares the emptying flow rate according to the venting water temperature of the tests, with the retort being cold. It can be seen that the higher the temperature, the greater the flow rates and hence the shorter the venting time.

In the tests carried out with the venting water at 60 °C and 70 °C, there was no further tendency for the retort emptying flow rate to be higher when the equipment was hot (Table 1 – venting time) since the retort did not heat the water up seeing as it was already at a higher temperature.

Steam is the element that helps the pump to remove the water from the retort due to the decrease in the pressure differential between the suction of the pump and the retort. With the influx of steam into the retort, always at a pressure of 3 bar, the steam heats the water–steam interface. The temperature of the water remaining in the retort continues the same since the heated water remains at the surface due to its lower density. The greater the difference between the temperature of the steam and that of the water, the greater the amount of steam required to heat the interface, and hence a greater amount of steam will be condensed.

At the beginning of the emptying process, when there is still a lot of water in the retort, the interface temperature, which is higher than that of the remaining water, does not interfere with the outflow of water. As the amount of water in the retort decreases, so the interface begins to influence the emptying flow rate, since the water is also being heated. Thus, according to Watt's principle (the steam pressure ruling the system is related to the lowest temperature (Folmer-Johnson, 1965)), the steam pressure increased with time due to the increase in the water temperature, and consequently increased the outflow rate of the pump, thus explaining why the flow rates were greater at the end of the emptying step.

In the same way, during the emptying of the retort, the higher the temperature of the water, the higher its flow rate, due to the corresponding steam pressure.

In all the tests carried out, there were no problems with the operating conditions. The total venting time varied from 2.5 min to 1.4 min, corresponding to Test 1 (room temperature) and Test 9 (80 °C), respectively.

Steam consumption for venting using water corresponds only to the emptying step. Therefore the steam usage time was 2.5 min with the water at room temperature and 1.4 min with the water at 80 °C. Obviously the steam consumption required to heat up the water in the tank should also be taken into consideration. However, it is worth pointing out that this water is recoverable and may be used in other venting stages. Hence steam is consumed to heat the water in the tank for the first venting, and from then on only to maintain its temperature. It should be pointed out that the venting water temperature depends on the initial temperature of the product, which, except in special cases, is always higher due to the stages prior to the sterilization process.

Table 1 shows the values calculated for the volume of water removed from the retort during the venting stage. The volume was calculated from the area under the curve of the venting water flow rate plotted against the time (Figs. 3 and 4), which remained between 0.23 m^3 and 0.20 m^3. Considering the accuracy of the integration, these values correspond to the volume of the retort, which is 0.22 m^3, making sure there is no water left in the equipment. These values may also serve for the continuity of this study, as a parameter indicating the end of the venting stage.

3.1.2. Distribution of the pressures and temperatures in retort water venting

In sequence, the evolution of the temperature distribution and the pressure in the retort with no load will be presented.

With the aim of tracing the pressure of the retort full of water in a few experiments (Tests 1, 3, 5, 7 and 9), the drain was opened and

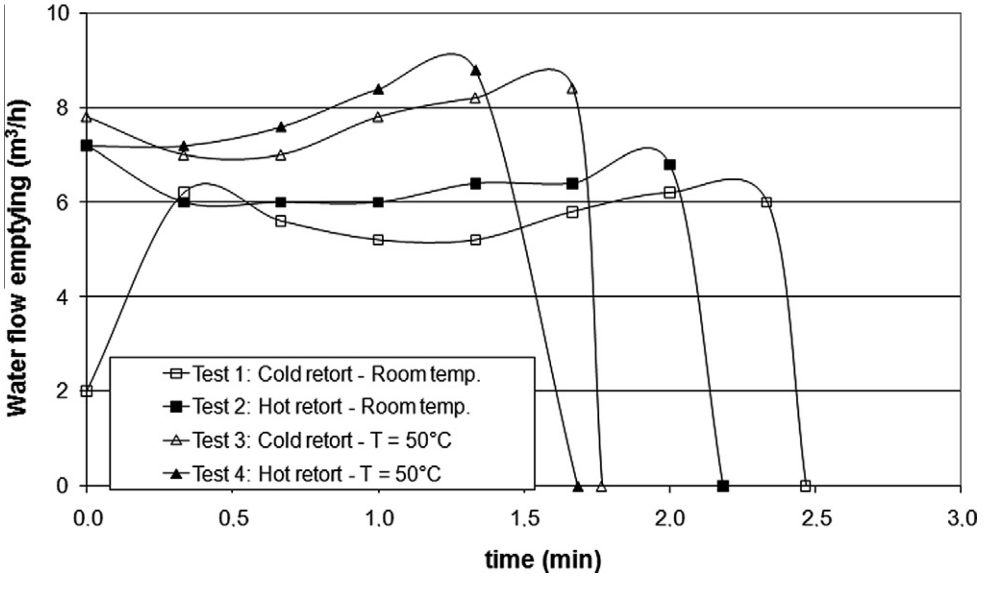

Fig. 3. Evolution of the emptying flow rates of the retort: water at room temperature and at 50 °C.

Table 1
Operating conditions and summary of the results obtained from the tests carried out at the venting stage of the retort with no load using water.

Test #	Water temp. (°C)	Retort temp.	Drain opening	Average flow emptying (m^3/h)	Water volume venting (m^3)	Time venting (min)	Pressure start venting (bar)	Vapor pressure (bar)
1	25	Cold	Yes	5.3	0.23	2.5	0.19	0.03
2	25	Hot	No	6.4	0.23	2.2	0.19	0.03
3	50	Cold	Yes	7.7	0.23	1.8	0.43	0.12
4	50	Hot	No	7.8	0.20	1.7	0.42	0.12
5	60	Cold	Yes	8.4	0.22	1.6	0.68	0.20
6	60	Hot	No	8.4	0.22	1.6	0.67	0.20
7	70	Cold	Yes	8.9	0.21	1.5	0.88	0.31
8	70	Hot	No	8.8	0.21	1.5	0.83	0.31
9	80	Cold	Yes	9.2	0.22	1.4	1.06	0.47

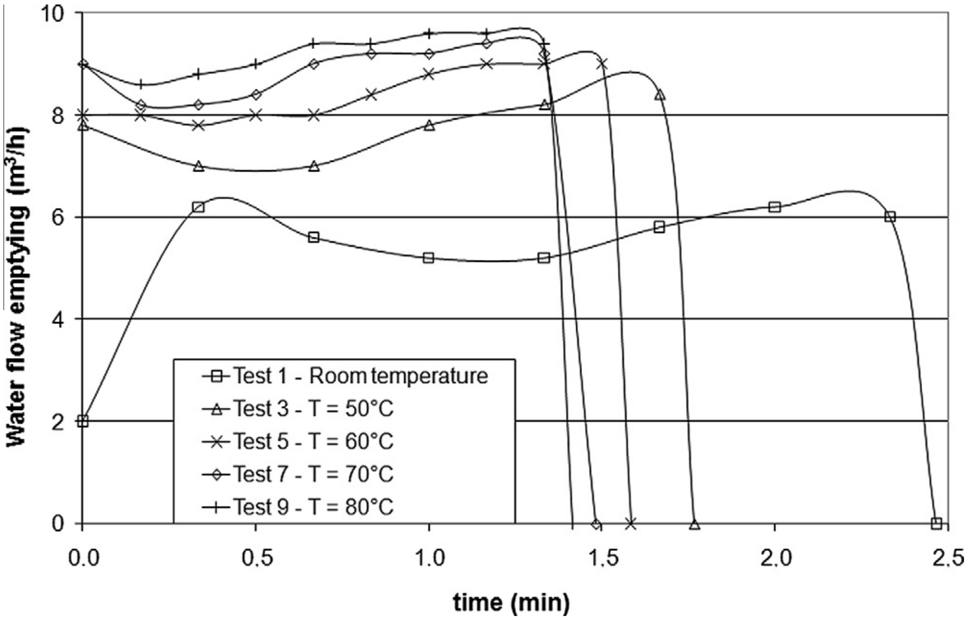

Fig. 4. Evolution of the emptying flow rates of the retort: variations with the water temperature. Retort being cold.

the pressure of the retort recorded in the niche position at the moment at which the pump was turned off, after having filled the retort completely. To do this, the two three way valves ([12] and [15], Fig. 1) were closed, thus isolating the retort from the water tank, and the drain opened. After registering the pressure for a short while, the procedure returned to its standard operation, as described in item 2.1. Due to the build-up of vacuum inside the retort, there was no outflow of water on opening the drain, except for the excess of water in the drain line itself.

In Tests 2, 4, 6 and 8, the drain was not opened. Only the pressure of the retort was recorded before opening the steam line valve and restarting the pump. The choice of tests for opening the drain or otherwise, was made at random.

3.1.2.1. Water at room temperature. As already mentioned, the water temperatures studied were room temperature, 50 °C, 60 °C, 70 °C and 80 °C. However, only the graphs for room temperature, 60 °C and 80 °C will be presented. Table 1 shows a summary of the results obtained for all the tests during venting, using water in the retort with no load.

During Test 1, Fig. 5, the retort was initially cold and its drain was opened for reading of the pressure in the niche, with the vessel full of water. Fig. 5 shows that the temperature of the retort remained at about 30 °C during the whole filling operation and the temperature of the retort began to rise as the steam entered at the upper end. The thermocouples, identified in Fig. 5 as TC, placed nearer the steam entrance, were the first to record a temperature rise. TC 1 was the thermocouple nearest the steam entrance and TC 6 the farthest (see Fig. 2). This behavior was repeated in all the other tests (see below), and may be seen better in Fig. 6, which shows the temperature rise of the thermocouples in Test 1 in greater detail.

At the start of the process ([1], Fig. 5) the pressure recorded in the retort corresponded to the atmospheric pressure in Campinas (0.94 bar) (source Cepagri – Unicamp), since the overflow and venting valves were open. With the filling of the retort, the pressure began to rise according to the restrictions at the water exit, reaching peak values during the closing of the venting and overflow valves ([2], Fig. 5).

Since the niche was set at 0.3 m above the drain in the retort, the pressure of the retort full of water and with the drain open was calculated by Eq. (1):

$$P_{retort(h)} = P_{atm} - P_h = P_{atm} - (\rho \cdot g \cdot h). \quad (1)$$

That is, the pressure of the retort full of water at a certain height h, $P_{retort\ (h)}$, is equal to the difference between the atmospheric pressure, P_{atm}, and the pressure of the water column corresponding to height h, P_h. Thus, for $h = 0.3$ m and the water density (ρ) at 30 °C = 995.7 kg/m^2:

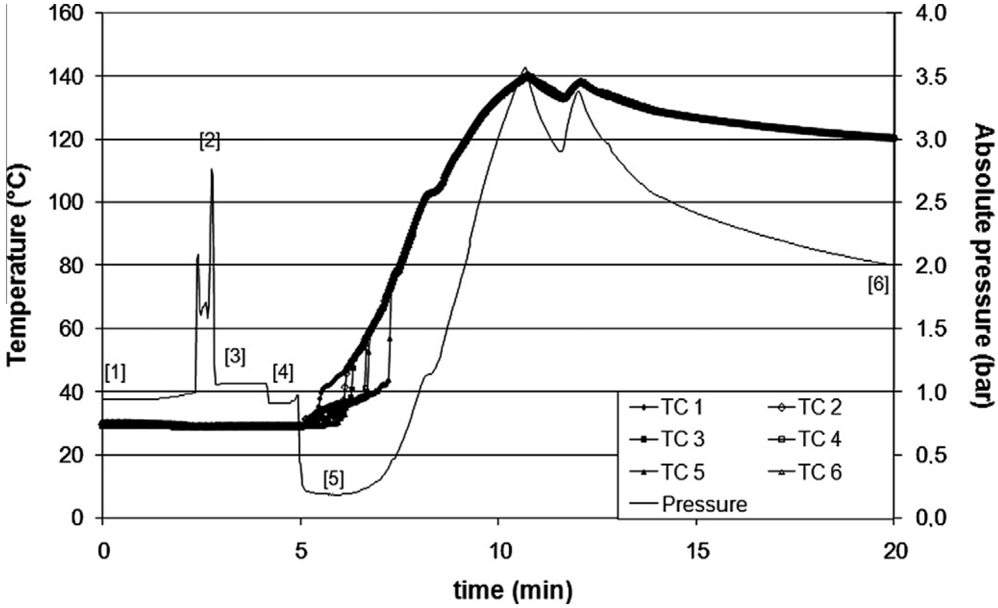

Fig. 5. Evolution of the temperatures and pressures during the venting stage: venting of the cold retort using room temperature water, Test 1.

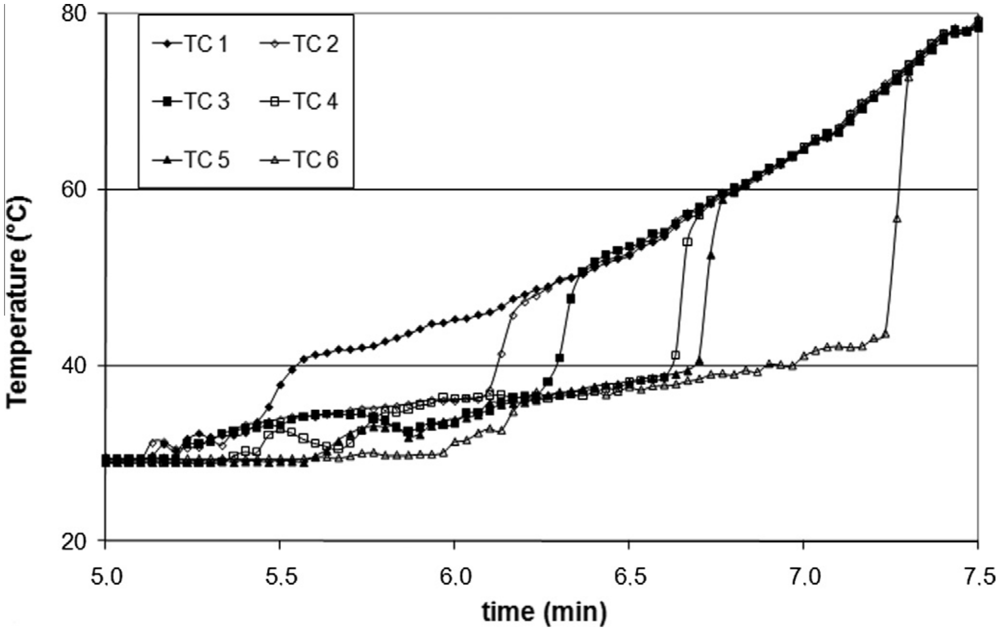

Fig. 6. Details of the thermocouple temperature rise, Test 1.

$$P_{retort(h)} = 0.94 - 0.03 = 0.91\ \text{bar}.$$

Since the water density varies very little in the interval from 30 °C to 80 °C and the height of the niche is unchangeable, when full of water and the drain open, the pressure of the retort (at the niche) was always 0.91 bar, independent of the temperature of the venting water. This value is indicated in Fig. 5, [4] and was also confirmed in later experiments. It is worth pointing out that during this survey the pump was turned off and the incoming steam valve closed.

Before opening the drain, the pressure inside the retort was 1.06 bar ([3], Fig. 5) right after the pump was turned off and the incoming water interrupted. When the pump was restarted at the beginning of venting, there was an abrupt drop of the pressure in the retort, reaching 0.19 bar ([5], Fig. 5), (Table 1 – pressure start venting). The pressure began to rise with the incoming steam, which aided removal of the water from the retort until the equipment reached its operating condition, that is, it reached the set temperature (121 °C), ([6], Fig. 5).

All the temperatures read on the mercury thermometer and those recorded by the thermocouples were within the limits required for a process to be considered as having suitable venting, that is, up to 0.3 °C, according to the protocols of the Thermal Processing Specialists. This was also observed in all the other tests shown below (Appendix A).

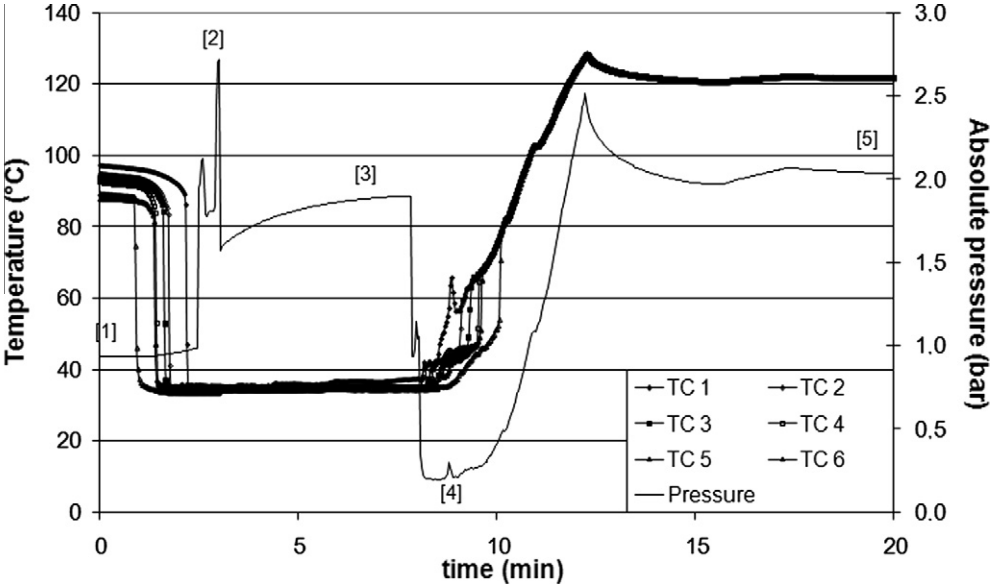

Fig. 7. Evolution of the temperatures and pressures during the venting stage: retort being cold and with venting using room temperature water, Test 2.

Fig. 7 shows the results obtained in Test 2, in which the venting water was at room temperature, the retort was hot and the drain was closed. The figure shows that the hot retort was cooled off by the incoming water at room temperature.

The pressure in the retort at the start of the process ([1], Fig. 7) was 0.94 bar, followed by an increase due to the water outflow restrictions ([2], Fig. 7). After turning off the pump and interrupting the incoming water, the pressure in the retort was 1.57 bar. This value increased throughout the whole time the retort pump remained switched off, as a function of the increase in the water temperature, reaching a value of 1.90 bar ([3], Fig. 7). The pump was then turned on at the beginning of venting, bringing about an abrupt drop in pressure, reaching 0.19 bar ([4], Fig. 7), (Table 1 – pressure start venting). The pressure began to increase with the incoming steam, which aided the removal of water from the retort until the equipment reached its operating conditions ([5], Fig. 7).

3.1.2.2. Temperature of the water = 60 °C. In Test 5, represented in Fig. 8, the retort was cold, the water was introduced at 60 °C and the drain valve was opened to read the pressure in the niche of the retort full of water ([4], Fig. 8). The pressure decreased throughout the entire time the retort pump remained switched off, reaching a value of 1.07 bar ([3], Fig. 8), due to the cooling off of the water by contact with the cold retort. The thermocouples also indicated a slight temperature drop during this period. When the pump was turned on at the beginning of venting, the retort pressure as shown in the niche was 0.68 bar ([5], Fig. 8), (Table 1 – pressure start venting).

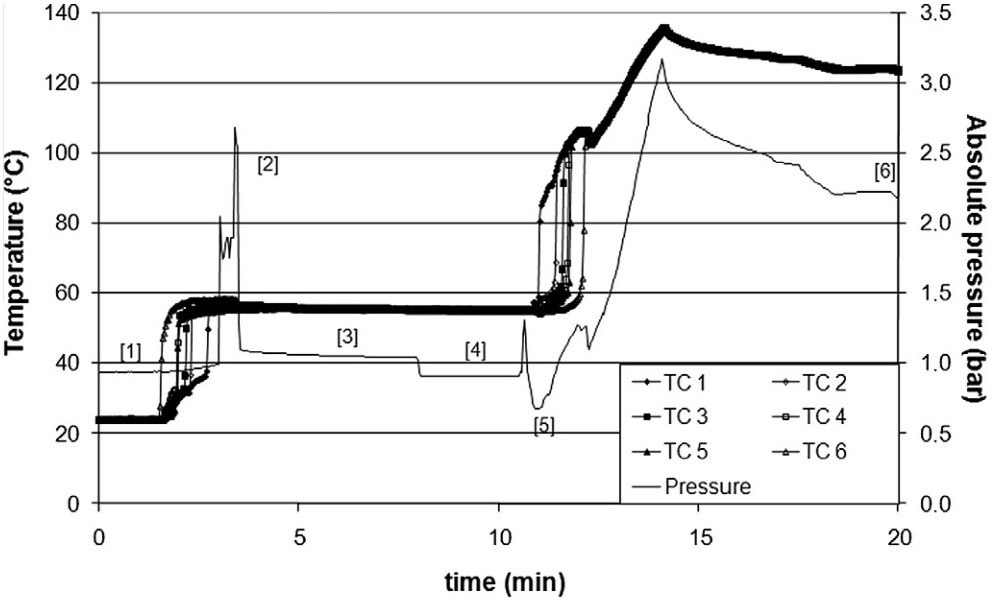

Fig. 8. Evolution of the temperatures and pressures during the venting stage: retort being cold and with venting using water at 60 C, Test 5.

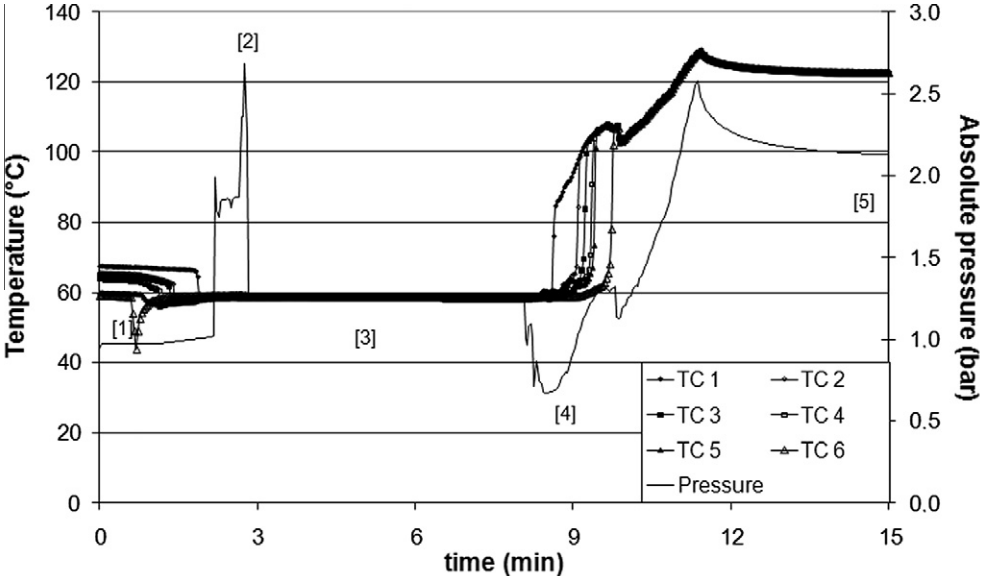

Fig. 9. Evolution of the temperatures and pressures during the venting stage: retort being hot and venting with water at 60 C, Test 6.

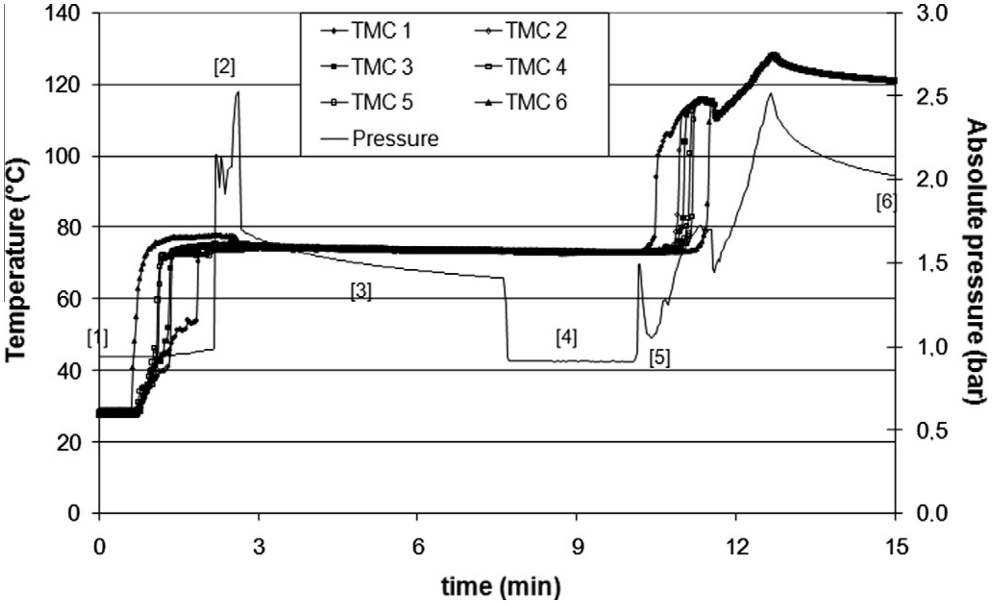

Fig. 10. Evolution of the temperatures and pressures during the venting stage: retort being hot and venting with water at 80 C, Test 9.

In Test 6, the venting water was again at 60 °C, but the equipment was hot and the drain was kept closed after overflowing. The evolution of the temperature and pressure of the hot retort in Test 6 is shown in Fig. 9. After turning off the pump and interrupting the inflow of water, the pressure in the retort was 1.24 bar, and this value subsequently decreased slightly, reaching 1.22 ([3], Fig. 9). Similar to Test 5, when the pump was switched on again, the pressure in the niche of the retort was 0.67 bar ([4], Fig. 9), (Table 1 – Pressure start venting).

3.1.2.3. Temperature of the water = 80 °C. In Test 9, as shown in Fig. 10, the retort was initially cold and the drain was open. In Fig. 10 it can be seen that the behavior was similar to the behavior in the previous tests, showing a drop of pressure in the retort due to it cooling off.

Table 1 shows a summary of the main results obtained under the operating conditions of the nine tests carried out in the study of the venting of a retort with no load. This study can be used as a subsidy for further research.

4. Conclusions

According to the studies carried out up to now, it can be concluded that the method of venting using water is very promising. The system set-up showed itself to be suitable for the venting of a retort having no load. From the results it can be seen that:

- Regarding the venting water temperature, the higher its value, the shorter the time for emptying the retort (Test 9), that is, a shorter venting time. Consequently, steam consumption during the venting stage would be reduced.

- The initial temperature of the retort, cold or hot, only has an influence on the water flow rate during venting of the retort when the water temperature is 50 °C or below.
- When the pump was restarted at the start of venting, the pressure dropped. In the experiment with water at 30 °C, the pressure of the retort was 0.19 bar when the pump was started; with the water at 80 °C this value was 1.06 bar. In all tests, these values were higher than the saturated vapor pressures at the respective water temperatures, Liley et al. (1984) (Table 1 – Vapor pressure) therefore causing no cavitation in the pump.
- The proposed methodology for the venting of a retort with no load was shown to be efficient in relation to the differences in temperature read on the mercury thermometer and the temperatures recorded by the thermocouples distributed inside the retort.

Acknowledgement

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Appendix A. Temperatures read on the thermometer and as recorded from the thermocouples

See Tables A.1–A.5.

Table A.1
Test 1.

Time (min)	Temperature (°C)						
	Thermometer	TC 1	TC 2	TC 3	TC 4	TC 5	TC 6
24.2	122.0	122.1	122.0	122.0	122.0	122.0	122.1
24.5	121.9	121.9	121.8	121.9	122.1	121.9	122.0
24.9	121.7	121.7	121.5	121.6	121.7	121.6	121.7
25.2	121.4	121.4	121.3	121.3	121.4	121.3	121.4
27.2	121.9	121.9	121.8	121.8	121.7	121.8	121.9
27.5	122.0	122.1	122.0	122.1	122.1	122.1	122.2
27.9	121.7	121.7	121.6	121.7	121.7	121.7	121.8
28.2	121.7	121.4	121.4	121.4	121.5	121.4	121.5
32.2	121.3	121.3	121.2	121.3	121.2	121.3	121.3
32.9	121.0	121.0	120.8	120.9	120.9	120.9	121.0
33.2	120.9	120.8	120.7	120.8	120.7	120.8	120.9
34.2	120.8	120.7	120.7	120.7	120.6	120.7	120.7

Table A.2
Test 2.

Time (min)	Temperature (°C)						
	Thermometer	TC 1	TC 2	TC 3	TC 4	TC 5	TC 6
22.0	121.7	121.7	121.6	121.7	121.5	121.6	121.7
22.3	121.7	121.7	121.6	121.7	121.5	121.6	121.7
22.6	121.7	121.7	121.6	121.7	121.5	121.7	121.7
23.0	121.7	121.7	121.6	121.7	121.5	121.7	121.7
25.0	121.7	121.8	121.6	121.7	121.5	121.7	121.8
25.3	121.7	121.8	121.7	121.7	121.6	121.8	121.8
25.6	121.8	121.8	121.7	121.8	121.6	121.7	121.8
26.0	121.8	121.8	121.7	121.8	121.6	121.7	121.8
30.0	122.0	122.1	122.0	122.1	121.9	122.1	122.1
30.3	122.0	122.1	122.0	122.1	121.9	122.1	122.1
30.6	122.1	122.1	122.1	122.1	121.9	122.1	122.1
31.0	122.0	122.1	121.9	122.0	121.9	122.0	122.1

Table A.3
Test 5.

Time (min)	Temperature (°C)						
	Thermometer	TC 1	TC 2	TC 3	TC 4	TC 5	TC6
24.0	123.0	123.0	123.0	123.0	122.9	123.0	123.1
24.2	123.0	123.0	123.0	123.0	122.8	123.0	123.1
24.5	123.1	123.1	123.0	123.1	122.9	123.1	123.1
24.9	123.2	123.2	123.1	123.1	123.0	123.1	123.2
27.9	123.6	123.6	123.5	123.6	123.4	123.6	123.6
28.2	123.6	123.7	123.6	123.7	123.5	123.7	123.7
28.5	123.7	123.7	123.6	123.7	123.5	123.7	123.7
28.9	123.7	123.7	123.6	123.8	123.5	123.7	123.7
31.9	123.1	123.1	123.0	123.1	122.9	123.1	123.1
32.2	123.1	123.0	123.0	123.1	122.9	123.0	123.1
32.5	123.0	123.0	122.9	123.0	122.8	122.9	123.0
32.9	123.0	123.0	122.9	123.0	122.8	122.9	123.0

Table A.4
Test 6.

Time (min)	Temperature (°C)						
	Thermometer	TC 1	TC 2	TC 3	TC 4	TC 5	TC 6
25.9	123.9	123.8	123.7	123.8	123.6	123.9	123.8
26.0	123.8	123.8	123.7	123.7	123.6	123.9	123.8
26.5	123.8	123.8	123.7	123.7	123.6	123.8	123.8
26.9	123.8	123.7	123.7	123.7	123.5	123.8	123.8
29.9	123.7	123.6	123.5	123.6	123.4	123.7	123.6
30.2	123.7	123.6	123.5	123.6	123.4	123.7	123.7
30.5	123.7	123.6	123.5	123.6	123.4	123.7	123.6
30.9	123.7	123.6	123.5	123.6	123.4	123.7	123.6
33.9	123.6	123.5	123.4	123.5	123.3	123.6	123.6
34.2	123.6	123.5	123.5	123.5	123.4	123.6	123.6
34.5	123.6	123.5	123.5	123.6	123.4	123.6	123.6
34.9	123.6	123.6	123.5	123.6	123.4	123.6	123.6

Table A.5
Test 9.

Time (min)	Temperature (°C)						
	Thermometer	TC 1	TC 2	TC 3	TC 4	TC 5	TC 6
19.0	121.4	121.3	121.2	121.3	121.2	121.3	121.4
19.3	121.3	121.3	121.2	121.3	121.1	121.2	121.3
19.7	121.3	121.3	121.1	121.3	121.1	121.3	121.3
20.0	121.2	121.2	121.1	121.2	121.0	121.1	121.2
22.0	122.0	121.9	121.8	121.9	121.8	121.9	121.9
22.3	122.0	122.1	121.9	122.0	121.9	122.0	122.0
22.7	122.0	122.2	122.0	122.1	122.0	122.1	122.0
23.0	122.1	122.2	122.1	122.2	122.0	122.2	122.2

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