Comparison of Cascade Control Technique for High Temperature Short Time Pasteurization System

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Abstract- **In this study control systems such as cascade, single loop and multivariable systems are compared for control of High Temperature Short Time Pasteurization are compared against each other using computer system. Here it is seen that how system cascade provides a much smoother temperature response curve compared to single loop systems even though they show a slower recovery. But this paper also shows how multivariable approach is able to recover faster and also show a much smoother temperature response curve. The temperature data recorded by the data acquisition system has recorded the data within an error limit of ±0.1℃ and thus the data acquisition system is a much complete way of measuring and recording the temperature data for this study.**

Index Terms- data acquisition; dairy; pasteurization; high temperature, short-time controls)

Abbreviation key: DAS = data acquisition system; FDV = flow diversion valve; LTC = LABTECH Control; PMO = Grade-A Pasteurized Milk Ordinance, 1993 Revision; STLR = safety thermal limit recorder.

I. INTRODUCTION

As defined in the Grade A Pasteurized Milk Ordinance, 1993 Revision (PMO) (10), the pasteurization of Grade A milk products requires that all particles of milk be held for a minimum of 15 s at 72℃ (161°F) or any of the seven time and temperature combinations listed. Safety controls for temperature, residence time, and differential pressure are used to ensure the adequacy of the pasteurization process and, thereby, the public safety of the processed milk supply. Before 1988, only mechanical recorders and controllers were allowed to control the pasteurization process. In 1988, the Milk Safety Branch of the FDA (6) issued memorandum M-I-88-11, which outlined the requirements for control systems based on computers or microprocessors for the pasteurization of dairy products.

Even though the computational capabilities of computers have increased, only computer-based controllers that control single variables have been successfully reviewed for compliance with the PMO (FDA does not approve equipment for milk pasteurization). No computer-based controllers that control multivariable process have been successfully reviewed for compliance with the PMO. Regulatory guidelines for the compliance of these multivariable computer controllers have not been established because of the lack of data on accuracy, reliability, and prevention of tampering.

All approved computer-based controllers still require circular or strip charts for recording of temperature data. These paper charts can easily be visually reviewed by plant management or regulatory inspectors, but this process is very time-consuming. An electronic review of data has the potential to be more accurate, more complete, and quicker than visual review. Massive amounts of data generated during pasteurization can be monitored, stored, and later reviewed by the computer to identify process deviations, such as sub-lethal pasteurization temperatures. Because few data have been published on the accuracy and reliability of these monitoring systems, they have not gained widespread acceptance by public health authorities (1).

II.MATERIALS AND METHODS

The HTST pasteurization system (Figure 1) was used to evaluate a computer-based system for controlling the dairy pasteurization process, acquiring data, and monitoring stored data. The HTST system consisted of a plate heat exchanger, a booster pump, a timing system based on a magnetic flow meter, an FDV, and a hot water heating loop (5). The heat exchanger was a multi-pass plate heat exchanger (CP model NMN; APV Crepaco, Chicago, IL) that operated at a rate of

1135 L/h. The booster pump was a 1-HP variable speed centrifugal pump (model 7C47; Tri-Clover, Inc., Kenosha, WI). The timing system used a 3-HP centrifugal pump (model CP no. 8; APV Crepaco). A magnetic flow meter (model IZM- 15-D; Accurate Metering Systems, Schaumburg, IL) was used to measure flow rate.

In the hot water loop for the heating section of HTST was a 2-HP model VAH centrifugal pump (Cherry-Burrell, Cedar Rapids, IA). The LTC software generated a 4 to 20 mA˚ DC signal to a pressure transducer (model 1000; Bellfram Co., Burlington, MA). The pressure transducer controlled a 12.5-mm, air-operated steam valve used in the heating of hot water for the heating section of the HTST pasteurizer. Differential pressure in the regenerator was monitored with an HTST differential pressure switch (model JD-222-306-A; Anderson Instrument Company, Inc., Fultonville, NY) using the 4 to 20 mA DC retransmission signal.

Three experimental studies were conducted using the HTST pasteurization system to show the effect of various process control strategies to temperature change on product temperature (2, 9). In the first study, a single loop control strategy, which is a traditional strategy, was used to control product temperature. This strategy used only the hot water temperature control to control process temperature indirectly. During a pasteurization run, the temperature of the product slowly decreased as fouling of the heat exchanger occurred.

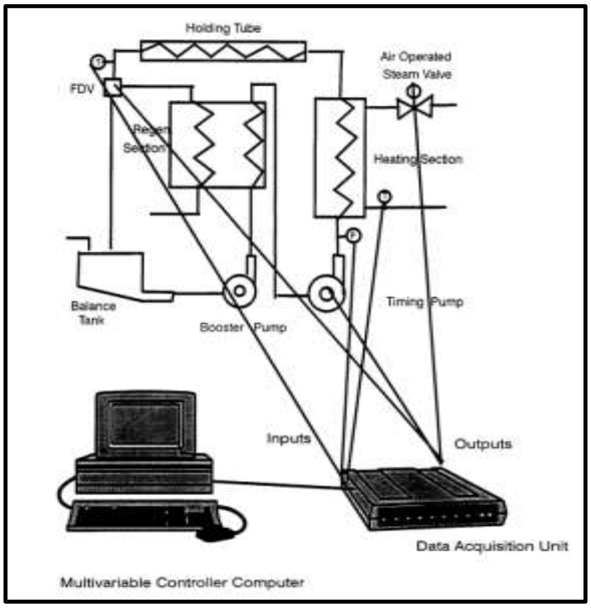

Figure 1.Schematic Diagram of HTST pasteurization system with computer control.

To improve performance, the second study used a strategy for cascade control, a modification of the single loop control strategy. The strategy for cascade control monitored both the product and water temperature to modulate the steam valve. The hot water temperature input was used for gross temperature adjustment and product temperature as a fine adjustment. In the cascade control loop configuration, the product temperature was used for the primary control loop and the hot water control for the secondary control loop.

The third study used a multivariable strategy using a cascade controller and residence time by computing a lethality process equal to legal requirements. The HTST system was under full computer control using the cascade control strategy. Pump speed was controlled according to the calculation of lethal rate times the maximum flow rate (Equation [1]).

$$LR_T = \frac{1}{TDT_T} = 10^{\frac{-(161\,°\mathrm{F} - T)}{8\,°\mathrm{F}}} \qquad [1]$$

Where LR_T = lethal rate at temperature T (time in seconds at 161 °F equivalent to 1 s at temperature T), TDTT = thermal death time, and T = temperature of processing in degrees Fahrenheit (4). For the experiment studying the single loop and cascade controllers, an FDV (model 262R; Tri-Clover Inc., Kenosha, WI) was used to control the diversion of flow. If the temperature of a product was less than 71.7 ℃ (161°F), product flow was diverted back to the balance tank. A program logic controller (model SLC 100; Allen-Bradley, Milwaukee, WI) was used for the FDV in the multivariable controller experiments. Total lethality at 71.7℃ (161 °F) was calculated from the temperature at the end of the holding tube and residence time from the flow meter signal. If total lethality was greater than 15 s at 71.7 ℃ (161 °F), a signal was generated to the FDV by the LTC software, allowing the FDV to move to the forward flow position. A lethality computation (Equation [2]) was used to control the program logic controller.

Table 1.Response of Single Loop Process Control to Temperature Changes on Product Temperature

	Temperature Change				
	73.3 – 76.1 ℃	76.1 – 78.9 ℃	78.9 – 73.3 ℃	73.3 – 76.1 ℃	76.1 – 73.3 ℃
Steady-state time, s	80	130	90	70	63
Mean Temperature, ℃	76.2	78.9	73.5	76.2	73.6
Minimum Temperature, ℃	75.7	78.8	72.9	75.7	73.1
Maximum Temperature, ℃	76.5	79.2	74.1	76.1	74.1
SD	0.22	0.09	0.30	0.25	0.27
Percentage of Temperature Set	99.96	99.92	99.82	99.89	99.75

EL= 〖10〗^((-(161 °F-T))/(8 °F))* 4500/GPH [2]

where EL = residence time (seconds), GPH = product flow rate in (gallons per hour), T = product temperature of processing (degrees Fahrenheit) (3).

Temperature data from the HTST pasteurization system was monitored to evaluate the accuracy of the DAS (6, 9). Mean, maximum, and minimum temperatures and standard deviations of data collected during processing for 55 min at steady state were used to evaluate the relative accuracy and machine drift between the pasteurization temperature recorded by a sensor wired directly to the DAS and that recorded on a circular chart by a HTST safety thermal limit controller (STLR) (model 352RV; Taylor Instrument, Rochester, NY). To verify the reliability of the DAS, the data were analysed for flow diversions and compared with those recorded on a circular chart by the STLR.

III.RESULTS AND DISCUSSION

The data for the processing conditions that were related to public health requirements using an HTST system were collected at 5-s intervals and stored electronically for further analysis. Approximately 0.5 MB of memory was required to record time and the five processing conditions for 8 h and 1.25 MB for a 20-h production run. When the sampling rate was changed from 5 to 1 s, the memory required increased to more than 6 MB. Because a file of this size cannot be placed on a 1.4-MB floppy disk, a tape recording was used.

Single loop experiments: Five temperature variations were assigned: 73.3 to 76.1, 76.1 to 78.9, 78.9 to 73.3, 73.3 to 76.1, and 76.1 to 73.3 ℃ . The single loop control showed rapid response to the temperature changes (Table 1). Between 80 and 130 s were required to return temperature to steady-state operation after the change was initiated. The mean temperatures were ± 0.2 ℃ of the set temperature for these changes. The temperature range was ± 0.8 ℃ of the set temperature. Standard deviations ranged from ± 0.09 to 0.30 ℃. All mean steady-state temperatures, determined after steady-state conditions were reached, were within 99% of the set temperature, which indicated that the product temperature attained the desired value for each variation tested. Temperature response curves from the single loop control showed the greatest deviation and the longest period of oscillation of all systems analysed. The single loop may achieve better control, and the system may become more stable at higher processing temperatures (not tested).

Cascade control experiment: This system showed slower responses to temperature changes (Table 2). The mean response time of 171 s for the cascade system was greater than the mean response time of 87 s for the single loop system. Mean temperatures were ± 0.1 ℃ of set temperature for each of these temperature changes. The temperature range was ± 0.3 ℃ of the set temperature. Standard deviations ranged from ± 0.12 to 0.19 ℃. Use of the cascade control system permitted more sensitive control of temperature and decreased the response speed of the system to the temperature changes. The temperature response curve showed smaller deviations and a shorter period of oscillation than did single loop control. The standard deviations from the use of the cascade controller were less than those from use of the single loop system. The steam valve control signal was more stable when controlled by the cascade controller than when controlled by the single loop controller (9); the cascade controller also delivered a more constant flow of steam instead of pulsing between high and low steam delivery. This smoother control was reflected in smaller product temperature deviations. More accurate control of the temperature was achieved by sacrificing quicker response time.

Multivariable control experiments: Both temperature and flow rate were controlled to achieve lethality with slightly more rapid response than did the cascade control (Table 3). The mean response time of 145 s was greater than the mean response time of 87 s for the single loop system. The mean temperatures were the same as the set temperature for all temperature changes. Temperature range was within ± 0.4 ℃ of the set temperature. Standard deviations ranged from ± 0.11 to 0.13 ℃. When multivariable control was used, any change in the flow rate resulted in a change of product temperature because the controller was maintaining a specific lethality. Multivariable control resulted in a smoother response such that standard deviations averaged ± 0.12 ℃.

All systems tested properly pasteurized and produced a safe product. If the temperature deviated below the legal minimum for temperature for the single loop or cascade controller, product was diverted. For the multivariable controller, if the computed value for the total lethality was less than 15 s at 71.7 ℃ , the product was diverted.

Table 2.Response of cascade process control to temperature changes on product temperature

	Temperature Change				
	73.3 – 76.1 ℃	76.1 – 78.9 ℃	78.9 – 73.3 ℃	73.3 – 76.1 ℃	76.1 – 73.3 ℃
Steady-state time, s	172	225	214	198	146
Mean Temperature, ℃	76.1	78.9	73.3	76.1	73.4
Minimum Temperature, ℃	75.9	78.6	73.1	75.9	73.1
Maximum Temperature, ℃	76.4	79.2	73.7	76.3	73.6
SD	0.19	0.12	0.15	0.12	0.14
Percentage of Temperature Set	99.99	99.99	99.98	99.98	99.96

Table 3.Response of Multivariable process control to temperature changes on product temperature

	Temperature Change				
	73.3 – 76.1 ℃	76.1 – 78.9 ℃	78.9 – 73.3 ℃	73.3 – 76.1 ℃	76.1 – 73.3 ℃
Steady-state time, s	174	144	171	139	136
Mean Temperature, ℃	76.1	78.9	73.3	76.1	73.3
Minimum Temperature, ℃	75.8	78.9	73.2	75.9	73
Maximum Temperature, ℃	76.4	79.2	73.6	76.4	73.3
SD	0.13	0.11	0.12	0.13	0.11
Percentage of Temperature Set	99.99	99.98	99.98	99.99	99.99

System response to power or equipment failure: The following effects on the computer control system were examined: steam pressure loss, air pressure loss to both the pneumatic steam valve and the FDV, booster pump failure, and complete power loss. In addition, the total lethality alarm operation, as used to control the flow diversion signal, was verified.

When the process flow rate was set at 1135 L/h and the temperature was set at 72.8 ℃, the HTST pasteurizer was designed to work with steam pressure in the range of 1.2 to 1.9 kPa. When the steam pressure fell below 0.86 kPa, energy was insufficient to maintain the HTST process at operating temperature. The process recovered as steam pressure climbed above 1.2 kPa. The nominal operating air pressure required for the steam valve was 0.72 kPa. In this study, when an air pressure of < 0.29 kPa was fed to the steam valve, the valve faltered, and the process temperature could not be maintained. The nominal operating air pressure that was required for the FDV was 2.4 kPa. As pressure dropped below 1.4 kPa, the FDV moved into its divert position. Recovery occurred when 1.4 kPa of air pressure was restored to the FDV. Booster pump failure was similar in its effect on the product temperature to a flow rate of 940

L/h. A sharp temperature increase was recorded as product flow slowed and then returned to normal. With the single loop system, temperature rose to 74.2 ℃, and, with the cascade system, the controller held the temperature increase to 73.7 ℃ before returning to the set temperature. Booster pump failure at 1135 L/h resulted in a very unstable flow rate because the variable speed centrifugal pump could not regain a steady flow rate. This flow rate fluctuation resulted in a temperature fluctuation in the product that was too erratic for the controller to control effectively. A test for complete electrical power loss to the computer control system was performed also by cutting the power simultaneously to the HP Vectra® and the HP 75000 card cage. All processing units reverted to fail-safe positions, resulting in complete system shutdown. Data showing process variables (temperature, flow rate, FDV position, and differential pressure) remained intact on the hard disk drive of the HP Vectra®. Upon completion of the experiment, this fault was corrected by implementing a file closing option in LTC. Data were recovered using the Disk-fix application in the PC Tools Deluxe software. This program converted the "lost" data by correcting the cross-linked file and the unattached cluster errors. The total lethality alarms operation, as used to control the flow diversion signal, was tested. As soon as process temperature dropped below 71.7 ℃ and the controller computations produced a value below 15 s, a signal was sent the FDV to divert product flow back to the balance tank. Future plans include incorporation of sensor audits into a control strategy and the field trial of a DAS in a commercial dairy.

Table 4.Comparision of temperature readings recorded by the data acquisition system with those recorded by the safety thermal limit recorder over 55 minutes of data collection

	Data acquisition System	Safety Thermal Limit Recorder
Time started, h	1408	1410
Time ended, h	1500	1505
Points, no.	3300	55
Mean Temperature, ℃	73.3	73.3
Minimum Temperature, ℃	72.6	72.8
Maximum Temperature, ℃	74.3	73.9
SD	0.20	0.20

IV.CONCLUSIONS

Cascade and multivariable control of an HTST pasteurization system reduced fluctuations in product temperature compared with the performance of single loop feedback control. Multivariable control was tested based on computations of product temperature that yielded equivalent lethality to 71.7°C (161°F) at 15 s. Multivariable control would allow operation at variable flow rates or at the most desirable temperatures for product quality. Dependent upon the dairy product manufactured and its quality parameters, product processing could be optimized to produce a more consistent product. These control techniques were easily implemented using computer control. Temperature and flow diversion data were monitored, stored, and reviewed. Accuracy of a data acquisition system was as reliable as a STLR.

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