The Time Factor in High-Temperature Short-Time Pasteurizing*

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Time and temperature are interdependent factors in the destruction of bacteria by heat. In the process known as high-temperature short-time pasteurization, the time-temperature conditions are 15 seconds and 160°F respectively. These are the conditions specified in the U. S. Public Health Service milk ordinance and substantially the same as those included in most state and local regulations. It has been shown by Weber,[1] in a review of the literature concerning the death of pathogenic bacteria of significance in milk by heat treatment, that this time temperature combination is not an absolute minimum. There appears to be included in this specification a safety zone of at least 9 seconds when 160°F is used and conversely of at least 5°F if the time is 15 seconds. Consequently there appears to be no need for an increase in either the time or temperature beyond those margins established by the fluctuations of the pasteurizer controls.

Unsatisfactory Time Control

The control of the time factor has neither received the attention nor undergone the development that has accrued to the control of temperature. There is intended no implication that perfection prevails in temperature control. Inspection of high-temperature short-time pasteurizers indicates that some will permit the forward flow of milk at temperatures less than the legal minimum. This condition is usually correctable by simple adjustment of the control instrument and is not the result of improper design nor lack of knowledge of the technique necessary for its detection. Pasteurizers of this type are normally equipped with thermometers accurate within ½°F and devices which both record the temperature throughout the entire operation and prevent the entrance of underheated milk into the pasteurized milk reservoir.

The same condition does not obtain with respect to the time factor. To date there has been reported no technique or device applicable to routine testing which will, with accuracy, determine the holding time of milk in high-temperature short-time pasteurizers. Neither are there available devices which will perform for time control functions similar to those of the recording thermometer and the milk flow stop.

In the absence of these controls, dependence has been placed upon other devices to assure a holding time of 15 seconds. In high-temperature short-time units, the holding time is the travel time of the fastest particle through the holder. Control is effected by sealing the pump at a speed which furnishes the proper holding time, but the determination of the holding period involves no standardized or generally accepted technique. It is the purpose of this paper to present certain experimental data on holding time testing and its application to routine inspection.

It would appear that a pasteurizer

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delivering a quantity of milk in 15 seconds equivalent to the capacity of the holder would fulfill the time requirement. It is well known that such a conclusion is erroneous. Flow velocities vary from the center to the pipe wall due to friction. Channeled flow results from the introduction of milk from a small pipe into the larger holding tube. Foam accumulation, resulting from air leaks and the escape of dissolved air upon heating, tends to reduce the effective cross sectional area of the holding tube. These and perhaps other factors make the travel time of the fastest particle less than the average velocity. Among the methods proposed for determining the holding time has been the measurement of the volume delivered for a time interval. By use of the formula

$$\frac{\text{capacity of holder}}{\text{volume delivered}} \times \text{time} = \text{Average holding time}$$

the average holding time may be computed but the travel time of the fastest particle is not given.

Other methods have involved the introduction of a traceable foreign substance. The 1939 edition of the Public Health Service milk ordinance and code [2] includes the timing of the interval between the injection of a dye solution such as fluorescein at the holder inlet and its appearance at the holder outlet as a suggested method for the determination of the holding time. This method has the limitation that the end point is difficult to detect and for that reason has in many places been supplanted by the salt injection technique reported by Fay and Fraser [3] Both tests are restricted to water in their application unless the adulteration of milk is permitted. It then becomes necessary to assume that water and milk have nearly identical behavior if the water results are to be used in timing the unit. It will be shown that this assumption is erroneous by unpredictable amounts.

Another method of testing has been to measure the time of travel of slugs of milk having a temperature different from that normally prevailing in the holder tube. Thomasson [4] has suggested the injection of cold milk with a measurement of the time interval between injection and a deflection of the thermometer at the outlet. A variation has been used in the development of automatic timers which record the time of travel of a slug of hot milk produced by a momentary by-passing of the temperature controller. These techniques possess an advantage in that no foreign substance is being introduced but it is obvious that, since the end point is determined by thermometric response, the quantities involved are far in excess of the particulate dimension specified.

USE OF SALT TEST

Of the testing techniques suggested, the salt test appears to present the closest approach to the criteria of tracing a single particle through the holding tube. The measurement of volume delivered and the temperature fluctuation methods appear to be the only tests applicable to milk. If an empirical correction could be established for either or both of these latter methods, it should be possible to determine the holding time of milk with a fair degree of accuracy. In these studies the results obtained from salt injection tests by the technique described below were used as the basis of comparison.

Test Technique. Test fluid was injected by means of a small hand-operated piston pump with the stem etched to indicate length of stroke necessary to deliver 50, 100, and 150 ml. quantities. The timing was started when the needle movement of a Meters Inc. model 35 d.c. milliameter indicated an increase in the conductance of the liquid crossing the electrodes at the entrance of the holding tube. The end of the holding time was similarly indicated by response to the change in conductance in the liquid crossing electrodes at the holder outlet. The milliameter was wired in series with a variable resistance to permit compensation for the conductance of water. The electrodes consisted of the severed ends of a standard 18 gauge rubber-covered copper wire. The area exposed was the cross-section of the wire and the distance of separation was the thickness of the insulation. The contact surface was located opposite to the direction of flow. Timing was by manually operated stop watches and the end points were the first indication of movement by the milliameter needle.

This instrument was found to give results entirely comparable with the Sol-u-bridge but a somewhat slower response was noted by an automatic timer. This was attributed to the larger amount of current required to energize the relays which operated the timer clock. The difference in time between two instruments varied from 0.9 to 3.50 seconds. This difference increased with decreasing velocity of flow.

TABLE 1

INFLUENCE OF QUANTITY INJECTED UPON THE HOLDING TIME AS DETERMINED BY SALINE INJECTION

Rated capacity of unit, lbs./hr.	*Average holding time when quantity injected was*		
	50 ml	*100 ml*	*150 ml*
10,000	15.7	15.6	15.5
10,000	16.8	16.4	16.4
12,000	20.0	19.9	19.8
15,000	16.6	16.5	16.4
15,000	14.0	14.0	14.0
20,000	15.4	15.4	15.5
20,000	16.4	16.1	15.9
22,000	17.2	17.3	17.3
30,000	15.3	15.3	15.3
Average	16.38	16.28	16.23

Comparison of Salt Test with Cold Injection

To compare the salt test with the cold injection test reported by Thomasson, a series of tests were run using injections of a saturated saline at 30°F ± 2°F. Quantities of 50, 100, and 150 ml. were injected and the time of travel determined by the changes in conductance as indicated by the milliameter and the change in temperature as indicated by both indicating and recording thermometers. Usually 5 trials were made for each size injection. The results reported here are tests on 9 pasteurizers, varying in rated capacity from 10,000—30,000 lbs. per hour.

It is conceivable that the injection of fluid into the holding tube could increase the velocity of flow. To determine the significance of this potential error the experimental results were tabulated to indicate the relation between the quantity of injectant and the holding time. In Table 1, it will be noted that the average difference in holding time between the 50 and 150 ml. injections is only 0.15 second. Consequently, it was concluded that variations within the range of 50—150 ml. had but little effect upon the holding time determination by the salt injection method.

Since it was apparent that the cold fluid injection test would require larger amounts of test fluid to produce a thermometer response than those required for the salt test, it did not follow that the above conclusion would necessarily hold. The results from the series of test runs using the deflection of the recording thermometer were tabulated and appear in Table 2. It will be noted that the difference between the extremes is 0.41 second and somewhat greater than the difference previously noted. It should also be stated that totally unsatisfactory results were obtained with the 50 ml. quantity in about 50 percent of the units tested, thereby limiting the reported data to the 9 units included in these tables. It is apparent that any empirical correction should be in terms of the quantity of injectant used.

TABLE 2

THE INFLUENCE OF THE QUANTITY INJECTED UPON THE HOLDING TIME AS DETERMINED BY THERMOMETRIC MOVEMENT

Rated capacity of unit, lbs./hr.	*Average holding time when quantity injected was* 50 ml	100 ml	150 ml
10,000	18.4	18.0	17.2
10,000	17.9	17.9	17.4
12,000	22.9	21.8	21.4
15,000	18.2	18.1	17.6
15,000	16.2	15.6	15.8
20,000	17.7	17.3	17.6
20,000	18.6	17.7	18.6
22,000	19.6	20.1	21.0
30,000	17.2	16.6	17.0
Average	18.52	18.12	18.11

COMPARISON WITH THERMOMETRIC RESPONSE

The next procedure was to compare the salt test results with those from thermometric response to ascertain whether a general correction factor could be derived. Table 3 presents the results from comparative tests on 16 units using a 100 ml. injection and readings at the recording thermometer. Experience showed this instrument to be more reliable than the indicating thermometer for this purpose. These results show the mean difference between the salt tests and the cold in-

TABLE 3

THE RELATION BETWEEN THE HOLDING TIME WHEN THE DETERMINATION IS BY SALT INJECTION AND BY THERMOMETRIC RESPONSE

	Average holding time by salt injection	*Average holding time by thermometric response*	*Difference*	*Deviation from mean difference*
	15.4	17.3	1.9	.09
	15.6	18.0	2.4	.59
	18.2	20.3	2.1	.29
	17.2	19.5	2.3	.49
	16.5	18.1	1.6	.21
	16.1	17.7	1.6	.21
	14.6	17.2	2.6	.79
	19.9	21.8	1.9	.09
	15.0	16.4	1.4	.41
	15.3	16.6	1.3	.51
	14.9	16.4	1.5	.31
	15.4	16.8	1.4	.41
	16.4	17.9	1.5	.31
	14.0	15.6	1.6	.21
	14.4	17.1	2.7	.89
	17.3	20.1	2.8	.99
Mean	16.01	17.82	1.81	

jection tests to be 1.81 seconds. If this were used as a general correction, the maximum error would be 0.99 second and 75 percent of the results would be within a range of 0.51 second.

In these tests, the timing was started with the milliameter needle movement and the difference in elapsed time attributed to the slower response of a thermometer. If this were the only variable, the variation in differences among the units studied could be attributed to the difference in sensitivity of the thermometers. A test series was run on one pasteurizer in which the speed of flow was varied. In this series, the holding time was also computed from the volume delivered. Table 4 indicates that the difference between the salt test time and the cold injection test was not constant but diminished with increasing velocity. Since the volume delivered would be expected to vary with the rate of flow, the correction applied here was proportional. When the computed holding times were multiplied by the factor 0.782, the relation between the first salt injection and volume delivered holding time determinations, it was found that a fair degree of agreement was reached between the holding times determined by the two methods at other velocities.

TABLE 4

RELATION BETWEEN HOLDING TIME DETERMINATIONS BY THE SALT INJECTION, COLD FLUID INJECTION AND VOLUME DELIVERED METHODS WHEN FLOW VELOCITIES ARE VARIED

1 *Average velocity ft./sec.*	2 *Holding time by salt injection*	3 *Holding time by cold injection*	4 *Corrected * Holding time cold injection*	5 *Holding time by volume delivered*	6 *Corrected ** holding time of volume delivered*
0.67	17.2	19.3	17.2	22.00	17.2
0.66	17.9	21.5	19.4	22.3	17.4
0.624	18.3	....	....	23.6	18.4
0.594	19.2	24.0	21.9	24.8	19.4
0.562	20.5	25.2	23.1	26.2	20.5
0.529	21.5	24.3	22.2	27.8	21.8

* Column 3 minus 2.1
** Column 5 × 0.782

Up to this point, holding times reported have been averages used without regard for limits of error. In applying the technique of cold fluid injection to milk, some recognition might be given to variations in running a series on a single machine. Limits of accuracy might be arbitrarily established as the summation of the average deviations from the three mean values used in establishing the holding time on milk, but in practice this procedure would only tend to lend confustion to the results. The use of mean values throughout is believed to be adequate protection from gross mistakes due to normal experimental error.

In applying the test to milk, the procedure followed has been to establish an empirical correction for each unit to be tested. A series of from three to five trials are made injecting cold saturated saline. Simultaneous determinations of the holding time are made by both salt and cold injection techniques. The difference between the mean holding times is used as a correction factor when cold milk is injected during pasteurization.

When determining the holding time by use of the volume delivered, gravimetric determinations are made if possible of the amount of water delivered in a time interval and salt tests are run concurrently. The weight of milk delivered is then determined for a similar time interval and the milk holding time estimated by the following equation:

$$\text{Estimated Holding Time} = \frac{W_m}{T_m} \times \frac{T_w}{W_w} \times \frac{T_{s.t.}}{\text{sp. gr. of milk}}$$

When W_m = weight of milk delivered in time Tm
W_w = weight of water delivered in time Tw
$T_{s.t.}$ = the holding time by the salt injection method

RESULTS OF PLANT TESTS

During the past year and a half there has been occasion to use tests to determine the holding time for milk in some 34 different units. In Table 5, it will be noted that comparison of the cold injection test with results from measurement of the volume delivered was possible in 9 plants. Of these, six (3, 6, 9, 11, 19, and 23) showed results comparable within reasonable limits, one

TABLE 5

HOLDING TIME OF HIGH-TEMPERATURE SHORT-TIME PASTEURIZERS ON WATER AND MILK

		Holding time on milk		*Ratio between holding times of milk and water*	
Plant number	*Holding time on water by salt injection*	*By volume delivered*	*By cold injection*	*By volume delivered*	*By cold injection*
1	17.3	18.0	16.3	1.040	0.942
2	14.4	....	14.6	.....	1.014
3	14.0	14.0	13.5	1.000	0.963
4	16.4	....	14.6	.....	0.889
5	15.4	....	15.8	.....	1.026
6	15.1	14.2	14.2	0.940	0.940
7	15.3	....	15.0	.....	0.98
8	18.4	....	16.9	.....	0.917
9	15.3	15.3	15.7	1.000	1.026
10	19.9	....	14.6	.....	0.733
11	14.8	14.7	14.8	0.993	1.000
12	15.9	15.0	15.9	0.943	1.000
13	16.4	....	14.6	.....	0.889
14	17.2	21.4	18.5	1.244	1.075
15	16.7	....	16.1	.....	0.964
16	18.3	....	17.8	.....	0.972
17	15.5	....	14.3	.....	0.922
18	18.7	16.4	....	0.876	.....
19	15.5	15.5	15.8	1.00	1.020
20	18.8	....	17.8	.....	0.946
21	16.2	15.7	....	0.968	.....
22	16.1	14.8	....	0.919	.....
23	24.6	21.6	22.2	0.877	0.902
24	14.9	14.4	....	0.965	.....
25	14.4	13.8	....	0.957	.....
26	16.9	15.6	....	0.923	.....
27	16.9	16.3	....	0.964	.....
28	15.2	15.2	....	1.00	.....
29	16.1	16.7	....	1.037	.....
30	16.2	14.8	....	0.913	.....
31	15.3	17.1	....	1.117	.....
32	16.3	16.86	....	1.035	.....
33	17.4	16.91	....	0.971	.....
34	15.7	13.4	....	0.853	.....

(12) indicated a reduced holding time by the volume-delivered method which was not reflected by the cold injection test, with one unit (1) the reverse was true, and the remaining unit (14) showed an increased holding time by both methods but not by comparable quantities. Since there appears to be little choice between the two methods, data by measurement of the volume delivered has been used in the more recent inspections. It has been found easier to convince the plant operator that the salt test on water does not hold for milk because the pump is delivering more milk than water than to lead him through a maze of empirical corrections.

The results from 34 plants indicated that 13 or 38.3 percent were undertimed. Of these, 5 (2, 3, 11, 24, and 25) showed a sublegal holding period on both milk and water. The condition on these units was attributed to changes in operation since the previous test. Four of these units had pump drives which would tend to speed up with belt wear. The other unit (11) was undertimed by but 0.2 second which is within the range of experimental error. Of the eight which remain, one (34) was due to the use of a cold injection test to time the unit without regard for correction and the other seven could be attributed to no other cause than the failure to account for the difference in the quantities of milk and water delivered at the same pump setting. This difference was not constant among the units tested. The relation between the amount of milk and water delivered appeared to vary from 0.734 to above unity.

There are listed here only the findings under normal operating conditions. More units would show short holding times if all contingencies had been anticipated. Among these contingencies is the holding time during diversion. The solution of this problem is still unsatisfactory in many installations. A usual practice has been to place a restriction in the diversion line to impede flow. If this restriction is sufficient to provide the same rate of flow as that prevailing during forward flow, the pressure within the valve must be the same during both conditions. The pressure during forward flow is the sum of the hydrostatic head and the head loss due to friction in the downstream line. The excess of pressure within the valve during diversion over that of the pasteurized milk immediately downstream must then equal the downstream head loss during forward flow. The pressure differential between raw and pasteurized milk may be considerable. It has not been exceptional to find the leak protection features of the flow diversion valve not operating. Common faults have been to find that oversize gaskets have prevented the opening of the leak escape valves and oversize on one gasket has prevented the other from seating. In view of these conditions, it is questionable whether the hazard of a shortened holding time is greater or less than the hazard of intermixture of raw and pasteurized milk at the flow diversion valve.

Those units which were using an auxiliary pump between the raw supply tank and the regenerator provided a satisfactory holding time under both conditions of operation when this pump was wired through the forward flow circuit only. This assembly however may provide unsatisfactory pressure conditions within the regenerator unless proper controls are employed. It is believed that this problem of holding time during diversion deserves exploration to secure a solution whereby both holding time and pressure conditions within the flow diversion valve are satisfactory.

IMPEDING DEVICES

Another group of contingencies stem from the U. S. Public Health Service Code requirement that the timing be done with all valves and any other flow impeding devices open to their fullest extent. The present trend of plant operators to include unit processes other than pasteurization in the pasteurizing line has complicated the problem of what constitutes a flow impeding device. In the course of testing units, it has been found that a clarifier in operation may decrease the holding time 1 second beyond the effect of a clarifier at rest and a cooling press may vary in its effect upon the holding time by the same amount depending upon whether coolant is being circulated. This problem becomes magnified when the operator locates a relief clarifier or a restricted by-pass to be used when the bowl of the first clarifier has filled up and cleaning is necessary. The logical pipe assembly would be and usually is to use a three-way valve which will permit milk to flow through either or both lines.

A similar operating situation may occur when milk is homogenized. In one installation the homogenizer was located between the regenerator and heater. Milk was supplied by the metering pump which was equipped with a by-pass to carry excess milk back to the supply tank. Since the setting of the metering pump had yielded a satisfactory holding time and since the by-pass line showed a small but continuous flow of milk, it was momentarily assumed that the situation could not be other than satisfactory. Test revealed that the holding time with the homogenizer was less by approximately one second. This was attributed to a lower head pressure at the pump during homogenization.

Since it is entirely possible for all of these conditions to be present on one unit, it is apparent that the sealed pump speed under these conditions would need to be at a point where the holding time was at least eighteen seconds during unimpeded forward flow or diversion, depending upon which was less. The absence of a positive time control independent of the pump seriously impares the flexibility of high-temperature short-time units. It is believed that time control in high-temperature short-time pasteurizing merits further study.

CONCLUSION

The practice of timing high-temperature short-time units during water runs permits errors of unpredictable magnitude. The variation in the amounts of water and milk delivered at the same pump setting may effect the holding time by as much as 26.7 percent. Because of this condition milk run tests should be used in timing. Both the volume-delivered and temperature-fluctuation techniques appear to have application in extending water run tests to milk by empirical correction.

REFERENCES

1. Weber, C. W. Safety Factors of H.T.S.T. Pasteurizers. *J. Milk & Food Technol.*, **10**, 14–27 (1947).
2. Milk Ordinance and Code recommended by the U. S. Public Health Service (1939 Edition). Public Health Bulletin, No. **220.**
3. Fay, A. C., and Fraser, J. Precision Testing of Short-Time High-Temperature Pasteurizers. *J. Milk Technol.*, **6**, 321–330 (1943).
4. Thomasson, H. L. New Test for High-Temperature Short-Time Pasteurizers. *Monthly Bulletin Indiana State Board of Health*, July 1945.

H. W. Dusterhoft, Deceased

The Wisconsin and International Associations have lost an active and faithful member in the death December 5th of Herman W. Dusterhoft. He had been sanitary inspector for the City of Waukesha for many years, and was a charter member and the first vice-president of the Wisconsin Association.