THE EFFICIENCY OF HOLDING TUBES USED IN HIGH-TEMPERATURE SHORT-TIME PASTEURIZERS

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The efficiency of a holding tube depends on the size of pipe used and the velocity of flow through the tube. Tests conducted on glass and metal pipe in sizes from one to four inches in diameter showed that, for a given capacity, highest efficiency can be obtained by constructing the holding tube of the smallest practical size of pipe. There was no difference between the efficiencies of comparable glass and metal holding tubes.

Introduction

The efficiency of a holding tube is usually defined as the ratio, expressed as a fraction or as a percentage, of the average velocity of flow in the tube to the velocity of the fastest measured particle. The average velocity is calculated from the rate of flow and the cross-sectional area of the tube; the velocity of the fastest measured particle is calculated from the length of the holding tube; and the holding time determined with a sensitive salt or dye test.

The higher the efficiency, the more nearly alike are the average velocity and the velocity of the fastest measured particle. Since much of the milk going through the tube travels at, or near, the average velocity, the amount of over-holding diminishes as the efficiency increases. A holding tube with high efficiency is, therefore, desirable.

It has been known, in general, that high velocities result in high efficiency, and it has been suspected that holding tubes of large diameter tend to have relatively low efficiencies for the conditions under which they are used in short-time pasteurizers. No specific data, however, have been published on this problem. In this study, data on the efficiency of holding tubes have been collected for the flow of water in holding tubes of 1-inch, 1½-inch, 2½-inch, and 4-inch sanitary metal pipe and of 1-inch, 2-inch, and 3-inch Pyrex brand glass pipe. The tubes were of selected lengths from 3 to 75 feet.

Experimental

Figure 1 is a sketch of the apparatus used for the tests. The set-up included a reservoir tank with hot and cold water inlets. Valves in the water lines were adjusted to give the desired flow of water at about 140°F. Water from the reservoir flowed to a constant-level tank providing a static head of about 9 inches of water at the inlet side of the pump. Depending on the capacity desired, a model 10, 25, or 100 Waukesha variable-speed, positive, sanitary milk pump was used.

The water was pumped through a multi-pass milk preheater heated by hot water, which in turn was heated by direct steam injection. The heating water was recirculated by a small centrifugal pump. The controls on the preheater were set to deliver heated water at 160°F.

After leaving the preheater the water passed through a three-way valve. This valve was used to obtain flow rates lower than those obtainable with the smallest pump (model 10) set at its lowest speed. When low flow rates were desired, this valve was set to discharge part of the water to waste and send the remainder through the holding tube. Constant flow rates as low as a few hundred pounds per hour could be obtained with this arrangement.

The water then passed through the selected holding tube which was mounted with a uniform slope of ¼" per foot. This slope was chosen as representative of those used in short-time pasteurizers. The water from the tube was discharged either to waste or to a tared receiver.

Holding tubes of 10 feet or less consisted of a single straight run; tubes longer than 10 feet had return bends between the appropriate number of straight runs of about 10 feet each. The tubes were mounted so that the return bends as well as the straight runs, had a uniform upward slope of ¼" per foot toward the outlet end. The length of each tube was measured from a tee at the inlet end to a tee at the outlet end. Electrodes used for the salt test were mounted in each of these tees.

The electrodes used at either end of the tube were identical. They were of the type described and illustrated in the 3A standard salt test.[1] Leads from each of the electrodes were connected to an automatic Solu-Bridge Flow Timer. This timer was checked and found to respond consistently to about 5

1. 3A Standard Method for Determining the Holding Time of High-Temperature, Short-Time Pasteurizers by Means of the Salt Conductivity Test. *J. Milk & Food Technol.* **13**, 261, (1950).

ppm of sodium chloride added to tap water at 160°F.

An injection of 50 cubic centimeters of saturated salt solution was used for all holding-time tests except for small flow rates of a few hundred pounds per hour. In this case injections of 25 cubic centimeters were used.

In making a holding time test, the flow rate was adjusted to give approximately a 15-second holding time and the system was operated until equilibrium conditions were established. The salt solution was injected through the electrode at the inlet to the holder and, when the salt charge reached the electrode at the outlet end, the holding time indicated by the timer was recorded. The temperature of the water at the outlet end of the tube was recorded and the discharge was collected for a timed period and weighed. This procedure was repeated about five times with each holding tube.

The length of the holding tube was then increased and the runs repeated. The same procedure was followed for the tubes of metal and of glass pipe in each of the available diameters. No air was added to the water in any of these tests and, as could be seen with the tests on glass pipes, negligible amounts of air were liberated from the water used in the tests.

The holding-tube efficiency was calculated for each run by the following formulae:

$$\bar{v} = \frac{w}{\rho A t}$$

where

$\bar{v}$ = average velocity, ft./sec.
w=wt. of water collected, lb.
ρ=density of water at measured temperature, lb./ft.^{3}
A = cross-sectional area of pipe, ft.^{2}
t = time for collecting water, sec.

and

$$vH.T. = \frac{H.\ T.}{L}$$

where

vH.T. = velocity of fastest measured particle, ft./sec.
H.T. = measured holding time, sec.
L = length of holding tube between electrodes, ft.

and

$$\text{Holding-tube efficiency} = \frac{\bar{v}}{vH.T.}$$

Reynolds number was calculated for the flow conditions in each run from the formula:

$$Re = \frac{D\bar{v}\rho}{\mu}$$

where

Re = Reynolds number
D = internal diameter of pipe, ft.
$\bar{v}$ = average velocity, ft./sec.
ρ = density of water at measured temperature, lb./ft.^{3}
μ = viscosity of water at measured temperature, lb/ft. sec. (viscosity in centipoises x 0.000672 = viscosity in lb./ft. sec.)

The graphs in figure 2 show the variation in holding-tube efficiency with Reynolds number in holding tubes of sanitary metal pipe. The graphs in figure 3 are for holding tubes of Pyrex brand glass pipe. The holding-tube efficiencies are plotted against Reynolds number since this parameter includes the diameter of the pipe and the average velocity of flow in the pipe as well as the density and viscosity of the liquid in question. In addition, the holding-tube efficiency for milk and for water is theoretically the same at the same Reynolds number in a given size of pipe. Thus, by using the appropriate values of ρ and μ for milk, the data can be applied to the flow of milk.

For water at 160°F the conversion factors which can be used to convert Reynolds number to the more familiar units of average velocity and pounds per hour, are shown in table 1.

The graphs in figures 2 and 3 indicate that holding-tube efficiency increases with Reynolds number rapidly at first, then more slowly, and becomes nearly constant at high Reynolds numbers. At each Reynolds number the efficiency decreases as the size (internal diameter) of the pipe increases. This is true for the various sizes of metal pipe and for the various sizes of glass pipe. The relationship also holds when metal and glass pipe are compared on a basis of internal diameter. The comparison cannot be made on the basis of nominal size since, with glass pipe, the nominal size refers to internal diameter, whereas the nominal size of metal pipe refers to its external diameter.

In comparing the efficiency of glass and metal holding tubes, the differences in the nature of the surfaces of these two types of pipe has no apparent effect. Nor does any apparent difference result from the sharp 90-degree elbows used in glass pipe as compared to the 90-degree sweep elbows used in metal pipe.

The data indicate that, for a given flow rate, highest efficiency can be obtained by using the smallest practical size of pipe. This means that relatively long tubes of small diameter and, hence, high velocities are most desirable.

The efficiency of a box-type holding tube was also measured. This tube consisted of seven 34 ¾-inch lengths of 2-inch metal pipe mounted one above the other. The slope

TABLE 1. CONVERSION FACTORS

Nominal size of pipe	To convert Re no. to average velocity in ft sec, divide by:	To convert Re no. to flow in lb hr, divide by:
Sanitary metal		
1-inch	17,068	17.50
1½-inch	26,517	11.26
2½-inch	44,827	6.66
4-inch	72,518	4.12
Pyrex brand glass		
1-inch	18,914	15.79
2-inch	37,836	7.90
3-inch	56,743	5.26

of the straight pipe portions of this tube was 0.15 inch per foot. The return bends between the straight lengths were in the form of machined recesses in the heads that fit over the tube ends.

Because of the design of this holding tube it was not possible to measure its total length. The length of 2-inch metal pipe equivalent to this tube was calculated from the value of the capacity of the tube supplied by its manufacturer. This length, 24.44 feet, was used in calculating holding-tube efficiency. A holding time of 15 seconds was obtained with this tube at flow rates of about 5,700 pounds per hour. This corresponds to an average velocity of 1.37 feet per second. The holding-tube efficiency for these conditions was found to be 84.4 percent. This is close to the value which might be predicted for a 2-inch metal holding tube of ordinary design.

THE EFFECT OF AIR ON HOLDING TIME

The effects of air on the nature of the flow of water in the experimental short-time pasteurizer were also studied. Although this information is not directly applicable to milk because foam in milk and air bubbles in water probably do not act the same, it is felt that these data will be useful in explaining some of the phenomena observed in checking the holding time in short-time pasteurization with the salt conductivity method.

Any air present in the system comes either from leaks in the joints in lines under partial vacuum or from dissolved air liberated when the water is heated. This air affects the measured holding time in two ways.

At the pump inlet it displaces water and causes a decrease in the rate at which the pump delivers water. The magnitude of this decrease in capacity increases as the amount of air leaking into the system increases. Also, the greater the vacuum at the pump inlet, the greater is the effect of a given amount of air entering the pump inlet. This is to be expected since, at lower absolute pressures, the volume of the air is greater and it displaces more water.

In the holding tube the air continues to displace water. This causes the actual velocity of the water moving through the tube to be greater than it would be for the same flow rate with no air present.

The effect that air has on the measured holding time is the net result of these two effects. It was found that as increasing amounts of air were metered into the suction line of the system to simulate air leaks, the holding time was nearly constant at first and then always increased. This indicates that the decrease in pump capacity at a given air rate more than offsets the increase in actual water velocities in the holding tube.

The following data shown in table 2, were obtained by metering into the suction side of a model 25 Waukesha pump. The holding tube was 29 feet long, of 2-inch glass pipe, and had a uniform slope of 1 inch per foot. The vacuum at the pump inlet was 1.4 inches of mercury and water entered the pump at 140°F.

There was no restriction at the discharge end of the holding tube, and the pressure in the holding tube was, therefore, somewhat lower than the pressure which would ordinarily exist in the holding tube of a commercial pasteurizer. Hence, the air in the holding tube of the experimental setup probably had a greater volume and displaced more water than would the same amount of air in the holding tube of a commercial pasteurizer. The increases in holding time found for the same air rates in a comparable commercial pasteurizer would, therefore, be greater than those indicated here.

Similar experiments were performed with the same holding tube mounted with slopes of ¼ and ½ inch per foot. In each case the results were nearly identical, indicating that the movement of air and water through the holding tube is not influenced by the slope of the tube if it is between ¼ inch and 1 inch per foot.

SUMMARY

Holding-tube efficiencies increase with Reynolds number rapidly at first, then more slowly, and become nearly constant at high Reynolds numbers. At any Reynolds number the holding-tube efficiency decreases as the internal diameter of the pipe increases.

For a given flow rate, highest efficiency can be obtained by constructing the holding tube of the smallest practical size of pipe.

The efficiencies of glass holding tubes and metal holding tubes are comparable. Neither the differences in their surfaces nor the differences in the types of elbows used had any apparent effect on the holding-tube efficiency.

The net result of air leaks in a pasteurizer operated on water is to cause an increase in holding time.

The slope of the holding tube, when between ¼ inch and 1 inch per foot, has little effect on the rate of change in holding time with the amount of air leaking into the pump.

TABLE 2. EFFECT OF AIR ON PUMP DISCHARGE AND HOLDING TIME

Air rate, cu ft/hr at 160°F and 1 atm.	Pump discharge lb H_2O per hr at 160°F	Holding time, seconds
0.0	7,970	15.09
3.6	8,020	15.08
4.6	7,850	15.09
5.9	7,610	15.38
7.4	7,260	15.83
9.2	7,100	16.07
12.5	6,630	16.43
15.3	6,240	16.17
20.1	5,760	17.08