A STUDY OF HIGH VELOCITY WATER AS A MEANS OF CLEANING SOILED SURFACES

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The machinery and methods used in the handling of milk and its products fifty to seventy-five years ago compare with equipment of the present day about as weapons of the cave dwellers compare with modern implements of warfare.

Sanitary methods were unknown; science or skill in connection with the handling of dairy products was dependent upon the cleanliness practiced by the producer.

One of the first steps in the direction of modern sanitation practices by the dairy industry was the founding of the Essex County Medical Milk Commission by Dr. Henry Coit in 1894. This organization was set up to provide standards for sanitary control of milk plants and their products (1).

Another great aid in the development of adequate dairy plant sanitation was the production of one of the first detergents called Dairymen's Cleanser and Cleaner produced by the Wyandotte Chemical Co. in 1900 (2). This compound was one of the first cleaning compounds placed on the market and was used as a cleansing aid by the dairy industry.

The Dairymens' Cleanser was capable of quick rinsing and still left all surfaces odorless. Such a preparation was the forerunner of the detergent industry which has been essential to the dairy industry with its multiplicity of utensils and equipment which must be kept clean and free of bacteria of all kinds.

Further improvement in plant sanitation has come about since 1920. The steady improvement of cleaning materials along with the introduction of stainless steel made it possible to produce a better quality product.

The methods used to clean the equipment in early milk plants varied from conscientious attempts by the better operators to do the best job possible with the limited cleaning methods available to outright filthy practices by the poorer operators.

The equipment in the milk plant consists of some 14 to 20 pieces of machinery. All this equipment is made of stainless steel, tinned copper, or some alloy suitable for milk handling. This equipment is connected by sanitary milk pipes in lengths varying from 10 feet down to 3 inches. In these lines are tees, ells, and valves. The amount of pipe varies from about 100 linear feet in small plants to as high as 10,000 linear feet in large plants.

Every piece of equipment and all sanitary lines are completely disassembled, washed, reassembled, and sterilized every day, 365 days per year. Today the general method employed for cleaning milk plant equipment is as follows:

1. After use, the lines and equipment are flushed with water.
2. All lines and equipment are disassembled.

3. All milk contact surfaces are washed using various solutions of commercial washing chemical compounds and various brushes, sponges, etc.
4. All lines and equipment are rinsed with clean water.
5. The equipment is reassembled.
6. Sanitization is effected by the use of hot water, steam , or chemical sanitizers.

In general, management has not taken a very great interest in the methods of cleaning and has tended to accept the expense of cleanup labor as a necessary evil. Very few plants break their labor costs down far enough to include cleaning labor as a separate item, and those that do, accomplish it in a rather hit or miss manner (12).

According to Sheuring and Henderson (11) one of the most expensive and time consuming tasks in the operation of a modern dairy is the complete daily disassembly, washing, reassembly and sanitization of sanitary pipes and fittings. Frequently, a special crew of men is hired to perform this job. Not only is the cost of labor a major item, but the sanitary pipes soon become dented and often need replacing, depending upon the amount of care they receive during daily cleaning operations.

The cleaning operation is not only expensive but also of great importance, yet according to Fowler (5), the poorest type workmen are usually given the job. Most dairy workmen do not consider the cleanup job a very desirable one. The cleanup man is constantly exposed to wet damp conditions which give rise to colds, rheumatism, etc.

Because of the recent manpower shortage of the war and post war periods there has been an increase in cleaning method investigations with the hope that better cleaning methods would give better results with less labor. From these investigations one very promising solution to the dairy cleaning problem has been found. This method is cleaning by circulatory means with the equipment so designed and constructed that it may be permanently assembled.

Formerly pipe lines were only taken down once or twice a week, and due to the improper cleaning and sanitizing methods the dairies were forced to daily disassembly.

A method to clean dairy pipes in the assembled position has long been the dream of milk plant operators since the birth of modern dairy industry. Because of the tedious and time consuming task of cleanup, any improvement offers the possibility of major economy.

The use of permanent pipe line, while new to the milk industry is not new to the food industry. For several years certain breweries have used sealed copper pipe lines through which wort is pumped daily. It has been reported that a large soup manufacturer uses stainless steel pipe to transfer vegetable juices from one department to another. Another vegetable processing company uses pyrex glass pipe lines for the same purpose. In none of these cases are the pipe lines taken down for cleaning. They are cleaned in the assembled position. The bacteriological tests, run on the assembled pipes, indicate that they are as clean, or in some cases cleaner than pipe which is dismantled, cleaned and reassembled daily.

One of the first dairies in the United States to test the assembled pipe method of cleaning was the Cornell University Dairy (11). This work was carried out as a cooperative project in conjunction with the Corning Glass Works in 1941. The Corning Glass Works furnished the glass piping for this experiment. The purpose of the Cornell study was twofold:

1. To determine the adaptability of glass pipe to the dairy industry.
2. To determine the sanitary condition of glass pipe which is cleaned in place by circulation of cleaning solutions as compared to stainless steel which was dismantled, cleaned, and reassembled daily.

The results obtained indicated that Pyrex piping cleaned in place can be kept bacteriologically as clean or cleaner than the stainless steel sanitary pipe which was cleaned by dismantling, washing, and reassembling daily. The results also showed that Pyrex pipe, properly cleaned in place, causes no measurable increase in the bacterial count of milk passing through it. It was also clearly indicated that Pyrex piping offers the larger milk processors tangible savings in cleaning time and labor when cleaned in the assembled position.

H. P. Hood and Sons Dairy Products (3) have been carrying on research along these lines with glass pipe since 1947 and their findings are similar.

For a number of years the dairy plants in Europe have been using circulatory methods for cleaning dairy equipment without disassembly. Fisker (4), and Posthumus (10) in papers presented at the 1949 Worlds' Dairy Congress describe systems used to clean dairy pipes by circulatory methods. One plant employing this method is located in Holland. Danish dairies have used pipe lines especially designed for flush washing since 1937.

The usual procedure followed in cleaning sanitary pipe lines in the assembled position is as follows:

1. Immediately after the milk run is completed, the lines are flushed with cold water.

2. A sponge 2½ to 3 times the diameter of the line is inserted in the inlet end, and then with the cold water pressure, it is forced through the entire line.
3. The line is flushed with water until the water runs clear.
4. A cleaning solution is circulated through the lines. Various types of detergents may be used. One containing a wetting agent is recommended. This detergent is mixed in warm water in the detergent tank, usually with a dosage of 0.25 percent to 1 percent by weight. This cleaning solution is recirculated through the lines by means of a pump for a period of 15 minutes to one hour. When this period is ended, a sponge is usually forced through the line by means of the cleaning solution to remove any deposit which still remains on the surface.
5. After draining the line, all parts such as valves, connections, pumps, and other equipment are dismantled, scrubbed and reassembled in the line.
6. The line is then sanitized by one of three methods:
   (a) The circulation of chlorine solution (at least 100 ppm).

(b) The circulation of hot water at 76° C. - 88° C., for 5 minutes.

(c) Low pressure steam (15 psi) was passed through the line until the complete system has reached sanitizing temperature.

7. The line is allowed to drain and then the ends are capped until the next run of milk.

In other branches of the food industry, as in canning plants, wineries, etc., the cleaning operation is not ordinarily as elaborate as in the case of milk. Frequently, it is adequate to wash out the line with cold water, and then follow with low pressure steam.

In comparing assembled and disassembled methods of cleaning the labor saving value of the former is self evident.

In all the experiments being carried out, or those completed on cleaning sanitary pipes and fittings in the assembled position, no mention is made of the possibility of mechanical and hydraulic principles as a method of cleaning; i.e., the use of high velocity water.

In testing high velocity water as a method of cleaning the following problems were presented:

1. The determination of a good flushing agent.
2. The determination of the best flushing apparatus.
3. The determination of an indicator of flushing efficiency.

As a flushing agent main water was adopted. It was felt that the use of detergents or hot water could be explored later. The main purpose was to obtain data which would demonstrate the activity of high velocity water as a cleansing agent.

The flushing apparatus consisted of the following:

1. A pump to furnish high velocity water.
2. A means of accurately measuring this velocity.
3. A tank for supplying and capturing the main water.

A 500 G.P.M. centrifugal pump fitted with a differential mercury manometer and stagnation tube was used to measure water velocity. The discharge was captured in a large rectangular concrete tank.

A soiling method was developed which could be used to indicate the cleansing efficiency of high velocity water.

This study is the introduction to a cooperative project to determine the practicality of high velocity water as a cleaning aid. Upon its completion the project will cover the following ten points:

1. Varying water velocities and flushing times.
   What is the effect on soil removal when flushing time is kept constant and water velocity varied?
   What is the effect on soil removal when water velocity is kept constant and the flushing time varied?

2. Varying pipe diameters. Do pipe diameters limit the application of high velocity water? Will an increase in pipe diameter affect the flow at higher velocities? How will soil removal in one pipe compare with that of others having different diameters, when subjected to the same water velocity and flushing period?
3. Varying time and temperature. Will the percentage of soil removed be increased or decreased when flushing time is constant and temperature increased or vice versa? Which factor should be varied, flushing time or temperature, to give the greater soil removal when water velocity is kept constant.
4. Varying lengths and shapes of pipes. How do velocities vary along pipes of different lengths? What is the effect of tees, ells, etc., on water velocity? What should be done to compensate for these factors?
5. Varying the surface tension. What is the effect of various surface tension depressants on soil removal.
6. Varying the densities of solutions. Will the density of a flushing solution have any influence on the soil removal? What will be the change in flushing velocity of a cleaning solution which is more or less dense?

7. Varying the chemical components of detergent solutions. How do various detergent solutions react on fat, carbohydrate and protein soils? What effect do they have on the soiled surfaces; i.e., pitting, etc.?
8. Varying circulation methods. What method is best suited when using high velocity water, a recirculation method or continuous flow? Which one gives the greater soil removal?
9. Gas entrainment in the solution. What effect do various degrees of gas entrainment have on the percentage soil removal?
10. Abrasive materials in the solution. Can abrasive materials be used? If so, do they have any effect on the soiled surface?

To date, point number one has been explored, and the experimental results presented.

EXPERIMENTAL METHODS

Three methods of measuring soil removal in dairy pipes were considered:

1. The measurement of percentage soil removal by a quantitative bacteriological method.
2. The measurement of soil thickness before and after treatment of the test sections.
3. The measurement of radioactive isotopes before and after treatment of the test section.

The results in this study were obtained by the quantitative bacteriological method. Quantitative bacteriological methods were used by Mallmann et al. (7) in their study of mechanical dishwashing, and by Peabody et al. (9) in their study on high pressure vapor cleaned surfaces. The previous development of a suitable soil (7), and utilization of a method, the accuracy of which had been tried and proved by the latter group of authors, were influencing factors in selecting the quantitative method. Though this method may not be the most accurate of the three mentioned, the method when properly used yields results measuring cleaning action dependably. The equipment and materials for carrying out immediate experimental work were available and the practicality of this cleaning method could be quickly determined by quantitative means.

If the results of this method are consistent, and significant data are obtained, both of the other methods will be used as check methods.

Bacteriological Technique

To determine the mechanical removal of soil during the flushing period a quantitative bacteriological technique was used. The methods employed were similar to those developed by Mallmann et al. (7) in their study of mechanical dishwashing. B. subtilis (6620) A.T.C.C. the same test organism used in these experiments was also chosen for this project. Spores of B. subtilis were used because they were heat resistant, grew easily on most solid media and the colonies could be readily identified on an agar plate.

The spore suspension was prepared by growing the organism on tryptone glucose extract agar in 32 ounce medicine bottles at an incubation temperature of 37° C. for 14 days. With the test organism a maximum sporulation was obtained after 14 days (Table 1). After the 14-day incubation period the organisms were washed off the agar surface with distilled water. Sterile glass beads were also used to facilitate breaking up of bacterial clumps thus producing a homogeneous suspension. The B. subtilis spores were washed and centrifuged several times to remove bits of agar and metabolic products. The B. subtilis suspension was heated to 80° C. for 10 minutes to destroy all vegetative cells and heat-susceptible spores. The suspension was quickly cooled, plated and placed in the refrigerator until used.

Test soil

To measure, by a quantitative method, the effectiveness of water velocity in removing a test soil, it was necessary to develop some method of holding the test organism on the stainless steel pipe sections. Unless some means of retention is used, most of the test organisms are removed mechanically and the number left is generally so small that significant data are difficult to obtain.

The test soil used was a modification of Huckers reported in 1943 (6). This modified soil was developed by Mallmann et al. (7) for their study of mechanical dishwashing. The amounts of the ingredients were changed, but the ingredients remained the same. After many trials with varying concentrations of each component the following soil was found acceptable:

Solution A.

1.	Homogenized peanut butter	30 gm
2.	Lard	16 gm
3.	Sweet butter	16 gm

The ingredients of A were placed in an Arnold steamer to melt. The ingredients were mixed by stirring with a glass rod.

Solution B.

1.	Distilled water	745 cc
2.	Cornstarch flour (Cleveland dry paste flour)	25 gm
3.	Condensed milk (Carnation)	105 cc
4.	Flour	60 gm
5.	Egg yolk powder	60 gm
6.	India ink	10 cc

Solution B was prepared, placed in a Waring Blender, and mixed for 3 minutes. After A was dissolved, and blended, it was added to B. The mass was then mixed again for several minutes in a Waring Blender.

Test organisms were added during the latter mixing period, so that the organisms were evenly distributed throughout; in addition to mixing, the violent agitation broke up bacterial clumps. The bacterial spore suspension was added just prior to soiling to avoid decomposition of soil components due to bacterial action. When test organisms were not used the soil was refrigerated until used. Fresh solutions were prepared weekly to avoid bacterial contamination, which may occur during soiling.

Soiling Operation

The test pipe sections were 1 1/8" in diameter, having a length of 2 feet (±) 1/16" with connecting fittings at each end. This length was chosen because of ease in handling and cleaning during the testing process.

The most efficient method of soiling the pipe sections was to connect the sections by two burette clamps to a weighted ring stand and secure them in the vertical position. Bored rubber stoppers fitted with glass tubing were inserted into the bottoms of the pipe sections, and the exposed end of glass tubing was fitted with a section of rubber tubing and a spring clamp.

At a given time the soil was poured into the top of the pipe section until full. The section was immediately emptied, the time required for filling and emptying was recorded. When the last section had been coated a draining period of 6 minutes was allowed before application of the second coat. The draining period between coats was to insure good adhesion of previous coats before another was applied. After the draining period for the third coat had elapsed the rubber plugs were removed, and the sections allowed to drain and dry.

The test sections were placed in the drying oven at a temperature of 60° C. for a period of four hours. After drying the pipe sections were tested immediately.

Flushing Operation

Following the four hour drying period the pipes were subjected to a predetermined water velocity for a given period of time. The water was supplied by a 500 G.P.M. centrifugal pump, which was recirculated through the test section.

The procedure employed for flushing each test section was as follows: (Figure I)

1. The pump was primed by removing entrained air from the pump casing.
2. Entrained air was removed from the manometer tube.
3. A test pipe section was attached to the discharge line.

4. The discharge valve was adjusted to obtain the desired manometer readings.
5. A stop watch was set off the instant water appeared from the discharge line.
6. The discharge valve was closed at the end of a fixed period of time, and the next test section connected.

Surging and turbulence were avoided by using the same diameter water pipe in the feed lines as that of the test sections. Thus no disturbance was set up due to water flowing from a pipe of larger diameter to that of a smaller or vice versa. The test sections were connected far enough from the pump itself to insure a smooth flow of water and a constant velocity. This would be difficult to maintain when connected close to the pipe inlet.

Procedure for removing soil

For every test run a set of four control sections was used. The average bacterial count of these sections was used to calculate the percentage soil removed during that run. Three test sections were carried at each velocity thus insuring an accurate estimation of the soil removal.

To determine the percentage removal of soil the controls and test sections were scrubbed out using sterile dairy pipe brushes, with 100 ml. of distilled water.

The pipe sections were secured in the vertical position, and sterile beakers were placed under them. (Fig. II) The inside of the pipes was moistened and scrubbed thoroughly, followed by rinses of sterile distilled water.

When the pipes were clean, which was determined by holding to a light and examining the inside surface, the brushes were rinsed with sterile distilled water which was collected in the respective beakers. The washings were then transferred to dilution blanks, shaken, and suitable dilutions were plated, using tryptone glucose extract agar (Difco). The plates were originally incubated for 48 hours at 37° C. and counted. This was later changed to a 24 hour incubation period at 37° C. as growth was sufficient at 24 hours to facilitate accurate counting. Although _B. subtilis_ is a room temperature organism, a 37° C. incubation resulted in a more rapid growth thus making a 24 hour count possible.

After counts were obtained the percent removal was calculated in the following manner:

$$\frac{\text{Average count of 4 control sections} - \text{Average count of 3 test sections}}{\text{Average count of 4 control sections}} \times 100 = \%\ \text{Removal}$$

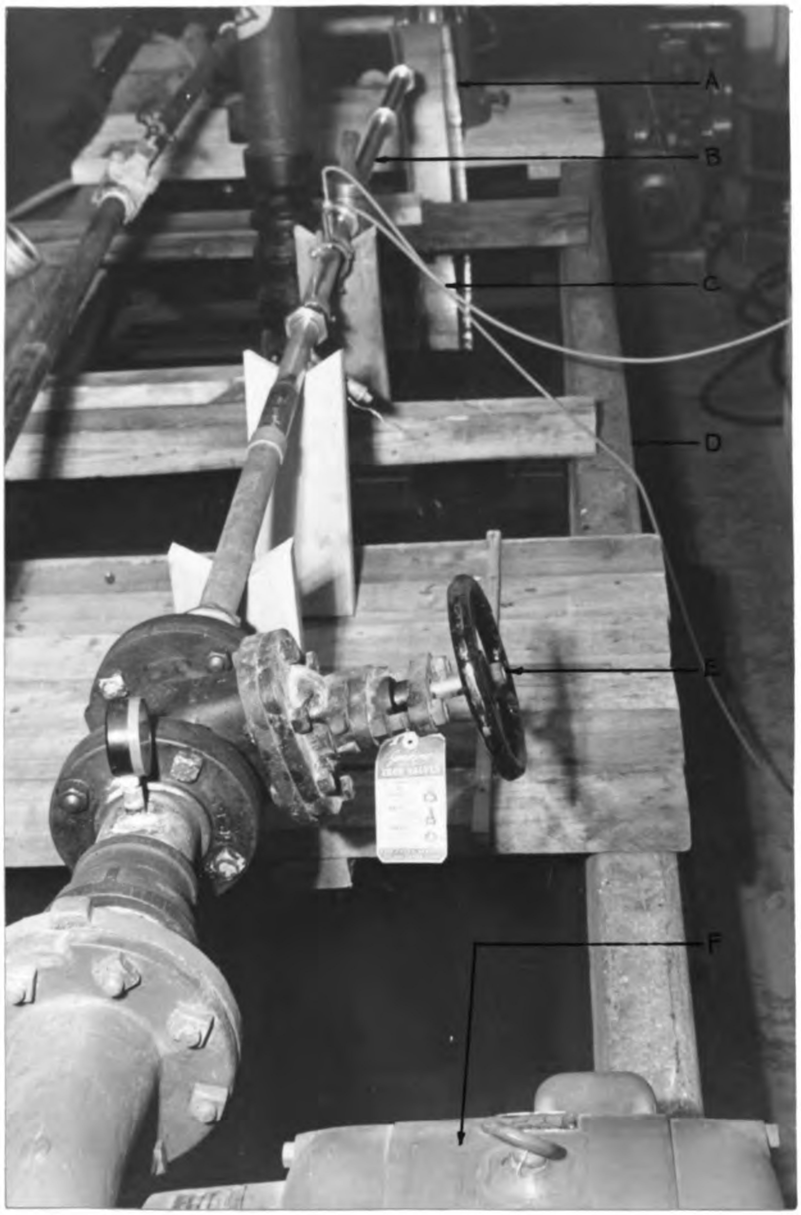

Figure I

A . . . . . . HOOD
B . . . . . . TEST PIPE SECTION
C . . . . . . LINES TO DIFFERENTIAL MANOMETER
D . . . . . . WATER TANK
E . . . . . . SHUT OFF VALVE
F . . . . . . PUMP

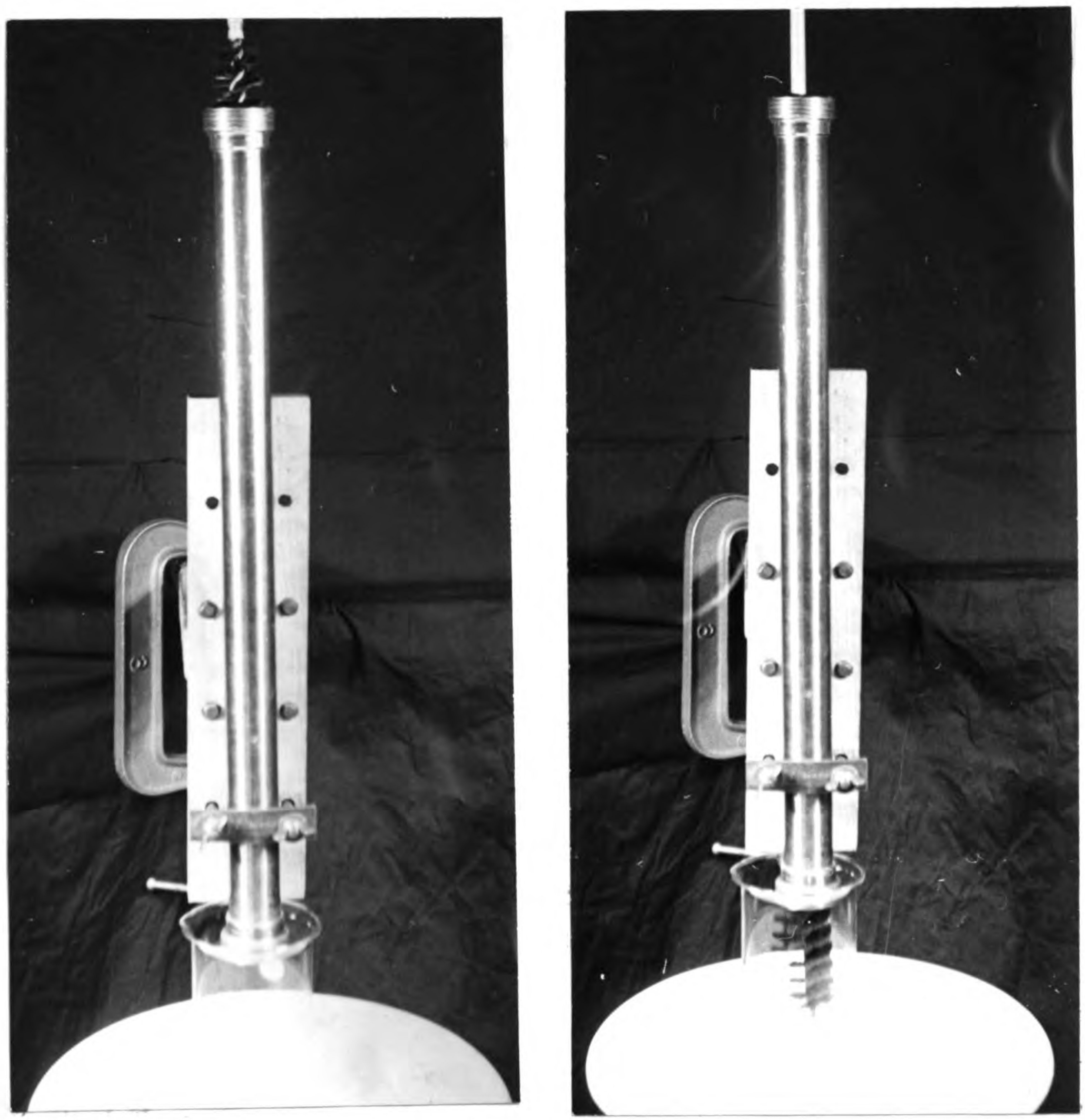

Figure II

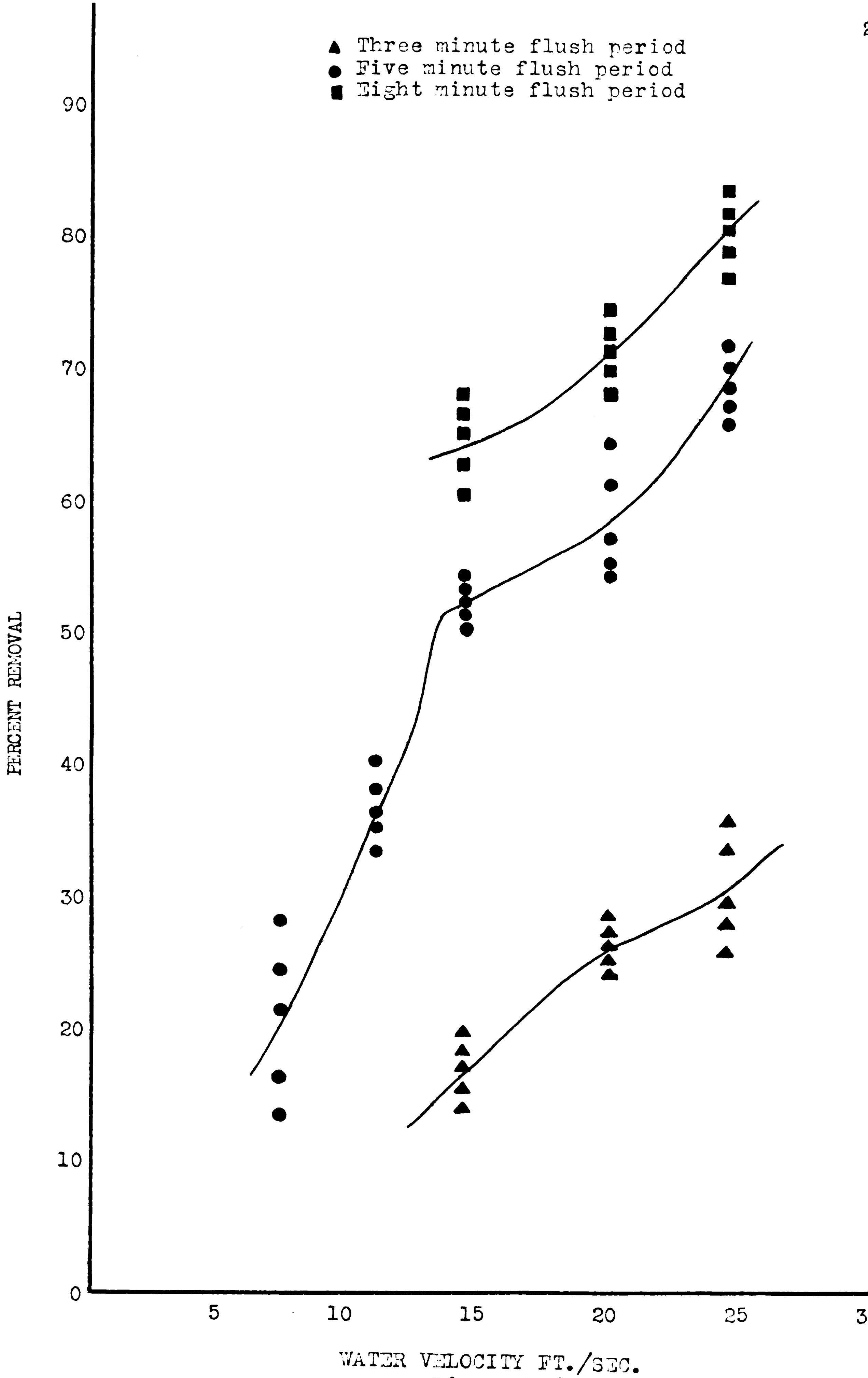
Three minute flush period
Five minute flush period
Eight minute flush period
PERCENT REMOVAL
0
10
20
30
40
50
60
70
80
90
5
10
15
20
25
30
WATER VELOCITY FT./SEC.

Figure III

TABLE I. SPORULATION OF B. SUBTILIS ON TRYPTONE GLUCOSE EXTRACT AGAR AT 37° C.

Incubation Period In Days	Percent Sporulation
4	38
6	57
8	72
10	84
12	87
13	89
14	89

TABLE II. PERCENT REMOVAL, AT THREE FLUSH PERIODS, OF BACILLUS SUBTILIS IN STAINLESS STEEL DAIRY PIPES AT A WATER VELOCITY OF 14.30 FT./SEC.*

Three Minute		Five Minute		Eight Minute	
Water Temp. C.	Percent Removal	Water Temp. C.	Percent Removal	Water Temp. C.	Percent Removal
17	16.0	19	55.4	18	68.2
17	19.0	18	53.0	18	66.0
16	18.3	18	50.4	17	65.3
15	20.0	18	52.1	15	62.8
15	14.2	17	52.0	15	61.0
Average					
16.0	17.5	18.0	52.6	16.5	64.4

*Represents five separate test runs.

TABLE III. PERCENT REMOVAL, AT THREE FLUSH PERIODS, OF BACILLUS SUBTILIS IN STAINLESS STEEL DAIRY PIPES AT A WATER VELOCITY OF 19.90 FT./SEC.*

Three Minute		Five Minute		Eight Minute	
Water Temp. C.	Percent Removal	Water Temp. C.	Percent Removal	Water Temp. C.	Percent Removal
16	27.5	16	57.4	16	72.1
16	26.4	16	54.5	16	70.0
16	25.0	16	64.5	16	75.3
15	28.1	15	61.5	15	68.7
14	29.8	14	55.2	14	55.6
Average					
15.4	27.3	15.4	58.6	15.4	68.3

*Represents five separate test runs.

TABLE IV. PERCENT REMOVAL, AT THREE FLUSH PERIODS, OF BACILLUS SUBTILIS IN STAINLESS STEEL DAIRY PIPES AT A WATER VELOCITY OF 24.20 FT./SEC.*

Three Minute		Five Minute		Eight Minute	
Water Temp. C.	Percent Removal	Water Temp. C.	Percent Removal	Water Temp. C.	Percent Removal
18	36.9	17	68.5	18	78.4
16	27.0	16	67.0	17	84.0
16	29.0	15	70.4	17	82.8
16	34.4	14	66.0	16	79.0
15	30.0	14	72.0	16	77.2
Average					
16.5	31.4	15.2	68.7	16.8	80.6

*Represents five separate test runs.

DISCUSSION:

Previous methods of cleaning have shown the important role high velocity water has played in the mechanical removal of soil.

The use of steam as a cleaning and sanitizing agent in dairy and food plants has been accepted for many years. With the development of portable steam generators, the advantages of vapor cleaning has been made available where a large generator was not practical. In addition, portable steam generators have the advantage of furnishing a high jet velocity line pressure. They have opened new fields for vapor cleaning in addition to sanitizing of the utensils, containers, etc., of the dairy or food plant. Many of these portable vapor cleaners have been used for the surface type of cleaning such as barn floors, stables and hog pens. Although studies have been made of the effects of "trapped" steam (e.g., inside a milk can) there is little information available as to the value of surface cleaning where sanitation is also of importance. It is obvious that steam delivered under pressure is an excellent means of cleaning and the experience of some operators indicates that there is a lowered incidence of disease when vapor cleaners are employed (9).

In making an evaluation of the method of vapor cleaning Peabody et al. (9) have shown that it is necessary to consider two separate phases; mechanical removal of the microorganisms, and lethal action of the heat or chemical agent. The mechanical removal of the soil was demonstrated by using _B. subtilis_ spores. The spores were resistant at the temperature of this test and therefore were a good indication of mechanical removal.

The lethal effect was demonstrated by using _Micrococcus caseolyticus_ as the test organism. The reduction due to the lethal effect was indicated by the viable cells present in the run off. The authors found that high pressure steam removed most of the test organisms by mechanical action.

Mallmann et al. (8) in their study of mechanical dish-washing machines demonstrated that an important phase in the washing action was the jet velocity pressures in the lower and upper wash arms.

In comparing machines in this study it was found that the machine with the higher jet velocity gave the greater percentage soil removal. This is clearly demonstrated when a comparison of machine A and E is made. Machine A with an average jet velocity of 7.1 gave a 91.2 percent soil removal with a detergent. Machine E with an average jet velocity of 3.2 gave a 0 percent soil removal without a detergent. These results have clearly demonstrated the importance of sufficient jet velocity in mechanical dishwashing. The data also showed that with a low jet pressure and low flow rate (Machine E) a low jet pressure and a high flow rate (Machine D) and a high jet pressure and a low flow rate (Machine C) gave unsatisfactory results. A high jet pressure and high flow rate (Machine A) gave excellent results. These results indicate that flow rate and jet pressure play important roles in determining the efficiency of mechanical dishwashing machines.

While high velocity water has been successfully employed as an aid in cleaning when in combination with other constituents, such as temperature, detergents, etc., an actual measurement and study of velocity alone has never been undertaken.

It was the purpose of this project to explore the possibilities of high velocity water as a cleaning method by checking the removal of a standard soil from stainless steel dairy pipes when they were subjected to various velocities for different time intervals.

Since the purpose of this project was to demonstrate the cleansing action of high velocity water, a cold water flush was used. Use of cold water insured that the soil removed was due to water velocity only and not to the detergency of warm water. It was discovered that a flush water temperature of 22° C. and above removed most of the soil at the higher velocities, and significant data could not be obtained. When flush temperatures of 19° C. and below were employed the temperature effect was eliminated.

In Figure III are presented the percentage soil removed from test pipe sections at various water velocities and flush periods. The average percentage removed at a jet velocity of 14.30 ft./sec. with a three-minute flush period was 16.5 percent, and at an eight-minute flush period 64.6 percent. These results indicate that an increased flushing period at a constant water velocity result in an increase in the percentage of soil removed.

The average percentage of soil removed as indicated by Tables II through IV , demonstrates that as the water velocity was varied and the flush period kept constant the percentage of soil removed increased as the velocities increased. This is shown by the following:

1. At a velocity of 14.30 ft./sec. (Table II) when a three-minute flush period was used the average percentage of soil removed was 17.50 percent.

2. At 19.90 ft./sec. (Table III) the average percentage of soil removed was 27.30 percent.

3. At 24.20 ft./sec. (Table IV) the average percentage of soil removed was 31.40 percent.

The above data indicate that increased water velocity results in increased soil removal.

The shearing action of high velocity water is demonstrated by the results obtained in Figure III. It should be noticed that at a water velocity of 14.30 ft./sec. and a flush period of 3 minutes an average removal of 17.50 percent was obtained. At the same velocity but a 5 minute flush period the average removal was 52.60 percent. When using an 8 minute flush period and the same velocity an average removal of 64.40 percent was obtained.

These results indicate that the longer the flushing period the greater the shearing action of the water, and as a result the greater the percent of soil removed at a given velocity.

The results of this cooperative project indicate that high velocity water may present another method of cleansing soiled surfaces, and therefore merits further investigation.

SUMMARY:

A method of soiling test pipe sections was presented.

A quantitative bacteriological method, using B. subtilis spores, for measuring soil removal was presented.

Increasing the flushing time, while keeping the water velocity constant increased the percentage soil removal.

Increasing the water velocity, while keeping the flushing time constant, increased the percentage soil removal.

There was an indication that a slight increase in flush water temperature resulted in an increased soil removal.

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