1505

DAIRY WASTE TREATMENT by aeration

THEORY
DESIGN
CONSTRUCTION
OPERATION

The calculations on pages 9, 10 and 11 are not correct. They do not follow the methods in use today. If a continuous process treatment plant is contemplated a competent sanitary engineer should be employed who specializes in milk waste treatment.

AGRICULTURE HANDBOOK NO. 176

AGRICULTURAL RESEARCH SERVICE

UNITED STATES DEPARTMENT OF AGRICULTURE

Acknowledgments

Members of the Dairy Research and Marketing Advisory Committee of the U.S. Department of Agriculture have offered many suggestions throughout the course of the investigations. The work of the members of the group currently known as the Dairy Industry Committee Subcommittee on Dairy Waste, of which E. C. Thompson is chairman, has been outstanding. H. A. Trebler, former member of the subcommittee, followed the work critically and gave worthwhile suggestions, as did A. J. Steffen and C. W. Watson, Jr.

The pilot plant study at the Pennsylvania State University was under the supervision of R. R. Kountz, Professor of Sanitary Engineering, who also designed industrial units from which practical information became available.

The continual interchange of ideas with W. W. Eckenfelder, Jr., of Manhattan College, was valuable, as he was one of the first sanitary engineers to apply these studies to other wastes.

Precaution

Dairy plant management should become acquainted with the requirements of the laws governing pollution control that pertain to the locality. The requirements usually specify that a registered professional engineer be retained to evaluate the problem, design the waste treatment plant, and obtain the proper approvals before construction begins.

Foreknowledge of special requirements may save considerable time and money and assure good relations between the dairy plant and the pollution control agency.

CONTENTS

Washington, D.C. *Issued July 1960*

For sale by the Superintendent of Documents, Government Printing Office, Washington 25, D.C. *Price 20 cents*

DAIRY WASTE TREATMENT by aeration

THEORY, DESIGN, CONSTRUCTION, OPERATION

By Nandor Porges, Thomas S. Michener, Jr., Lenore Jasewicz, and Sam R. Hoover, *Eastern Utilization Research and Development Division, Agricultural Research Service*

Waste water disposal is an important consideration in every dairy plant. The direct discharge of untreated waste waters into streams, public sewer systems, or onto land is frequently not possible or permissible. In such instances, it is necessary for dairy wastes to undergo treatment before disposal. Information available from investigations conducted at the Eastern Utilization Research Laboratory shows the technical possibility of providing adequate treatment for any quantity or concentration of dairy waste material. This Agriculture Handbook presents laboratory and pilot plant data of value to dairy plant personnel and sanitary engineers and gives details for planning and installing treatment systems using aeration.

GOOD HOUSEKEEPING AND POLLUTION

Wastes produced in operating a dairy plant vary greatly according to the products made and to housekeeping practices. The approximate quantities of waste present in various dairy process waters are listed in a guide, the "Manual for Milk Plant Operators" of the Milk Industry Foundation (*16*).[1] Losses range from less than 1 percent to more than 3 percent of the milk received, depending on the complexity of operation. Wide variation occurs in the amount of water used for washing and cooling. Well-operated dairy plants may use a gallon or less of water for each quart of milk received, whereas others may use more. However, when the cost of treatment is considered, dairy operators will find good reasons for making every effort toward waste elimination and good housekeeping.

A small dairy plant that receives 10,000 pounds of milk per day may produce each working day about 1,250 gallons of waste with a milk solids concentration of approximately 0.1 percent, or 1,000 parts per million (p.p.m.). This is the same as mixing 100 pounds of fluid milk with 1,237 gallons of water. The polluting effect will be at least 4 and possibly 8 times as great as the same amount of municipal sewage, and the dairy waste will require as much treatment as the waste from 40 to 60 persons. If wastes equal to 100 pounds of milk were dumped into a lake, the resulting bacterial action on this amount of food would require all the oxygen dissolved in approximately 200,000 gallons of saturated lake water for complete oxidation of the food material. Until the bacterial demands for oxygen are satisfied, no oxygen would be available in this part of the lake for fish or plant life. It is this tremendous polluting effect that makes treatment necessary for such high oxygen-demanding waste before it is drained into natural water courses.

ESSENTIAL INFORMATION

Extensive investigation on the bio-oxidation of dairy wastes established the amount of oxygen required and the rate at which oxygen must be supplied to treat dairy wastes successfully (*17*). Treatment consisted of two major phases. During the first, or assimilation, phase, sludge bacteria rapidly consumed the food in the milk waste and required oxygen at a high rate (*8*). During the second, or endogenous, phase, because these bacteria received no new food supply, they digested themselves and used considerably less oxygen (*6*). Endogenous respiration also occurred during the assimilation process. The successful application of these biological principles to the treatment of dairy waste is dependent on the following information, which is based on laboratory and pilot-plant investigations.

(1) Each pound (dry weight) of the organic matter in dairy waste (equivalent to about 10 pounds of wasted fat-free fluid milk) requires about 1.2 pounds of oxygen for complete oxidation. This oxygen requirement is termed the "chemical oxygen demand" (COD) and can be determined by a rapid method (*19*) described on

[1] Italic numbers in parentheses refer to Literature Cited, p. 15.

p. 18. Of the total solids present in dry nonfat milk, about 83 percent are organic; thus, a unit weight of dry nonfat milk requires a unit weight of oxygen.

(2) During the rapid assimilation of food, bacteria need about 37.5 percent of the total oxygen requirement, or $1.2 \times 0.375 = 0.45$ pound of oxygen per pound of organic matter.

(3) About 0.52 pound of new bacterial cell material is formed from each pound of waste in the assimilation phase.

(4) Nitrogen is often needed in the treatment of cheese plant wastes and may be added in an available form, such as ammonium salts, ammonia, urea, or casein. Nitrogen resulting from the breakdown of self-digesting sludge is also available for re-use.

(5) Rapidity of oxygen utilization and sludge formation in the assimilation phase depends on the quantity of seed bacteria present. Good results were obtained by using the sludge itself as bacterial seed for later additions of dairy waste. When the dry weight of sludge cells equaled the dry weight of the incoming waste solids in a single-dose feeding, assimilation was completed within 3 hours at 90° F. If the seed sludge was doubled, assimilation time was halved; if sludge was halved, the time required for waste assimilation was doubled (*7*).

(6) Sludge respiration requires the remainder of the total oxygen (COD) to oxidize the newly formed sludge: $1.2 - 0.45 = 0.75$ pound of oxygen for each 0.52 pound of sludge produced, or 1.44 pounds of oxygen required for oxidation of each pound of ash-free sludge.

(7) During endogenous respiration at 90° F., the sludge will normally consume itself at approximately 1 percent per hour. The hourly rate of oxygen demand of the sludge during self-digestion is, therefore, $1.44 \times 0.01 = 0.0144$ pound of oxygen per pound of sludge in the tank. The rate may be much lower at times (*6*, *14*).

(8) A pound of well-aerated dairy waste sludge usually occupies a volume of 0.8 cubic feet, or 6 gallons, after it is allowed to settle for 30 minutes (*12*).

It is apparent, then, that the effluent of the dairy must be studied and measured before a practical treatment plant can be designed. The maximum volume of waste must be known to establish the proper tank size. The characteristics of the rate of flow are needed to establish the rate and duration of supply of oxygen. The volume and rate are readily obtained by metering or collecting the waste in a calibrated tank. The temperature should be observed to insure that the waste is not too hot or too cold for bacterial activity.

The oxygen demand or strength of the waste must also be determined. The official chemical test or the rapid one described on p. 18 may be used. The chemical oxygen demand (COD) is the amount of oxygen required for complete oxidation of the organic substances and is usually reported in parts per million (p.p.m.). It is practically equal to the ultimate biochemical oxygen demand (BOD) for milk wastes.

Formula (1) may be used to obtain the actual pounds of oxygen for the total milk waste:

Total oxygen (lb.) =

$$\frac{\text{COD (p.p.m.)} \times \text{total waste (lb.)}}{1{,}000{,}000} \qquad (1)$$ [2]

Calculations from the above information will determine the capacity of the aeration tank, the quantity of seed sludge, the production of new sludge, and the oxygen requirements for the entire process. At this point, a decision to select a fill-and-draw (batch) system or a continuous operation process must be made. The fill-and-draw system is simple to construct and to operate and will be covered first in this Handbook. Fill-and-draw units that handle up to 40,000 gallons of waste daily are now in operation, and larger sizes are feasible. These units work well for dairy plants that confine their operations to an 8- to 10-hour workday. When round-the-clock operations are necessary, continuous treatment units that can process any quantity of wastes are probably more suitable. Both systems can be completely automated by the installation of timers, switches, and power-operated valves.

BATCH TREATMENT PLANT

Simplicity of operation makes a batch, or fill-and-draw, treatment of milk waste an attractive process for plants running on an 8- to 10-hour workday schedule. The designs suggested here are based upon operating conditions used in the pilot-plant studies made at the Pennsylvania State University, as sponsored by the Eastern Utilization Research and Development Laboratory (*11*). Similar plants have been constructed, utilizing the same method of operation. It is believed that any treatment unit designed accordingly and properly maintained and operated should also perform satisfactorily.

---

[2] Numbers in parentheses at right refer to formula designation.

SAMPLE CALCULATIONS

To demonstrate the calculations used to design a batch-type waste treatment plant, consider for example, a dairy that produces a maximum daily waste volume of 10,000 gallons containing 1,500 p.p.m. COD.

(*a*) Total oxygen requirement from formula (1):

$$\text{Total oxygen (lb.)} = \frac{1{,}500 \times 10{,}000 \times 8.34}{1{,}000{,}000} = 125 \text{ pounds}$$

(*b*) Oxygen for assimilation (37.5 pct. COD):

$$\text{Oxygen (lb.)} = 125 \times 0.375 = 46.9 \text{ pounds}$$

(*c*) Waste organic matter, ash-free, dry basis (83.3 pct. of COD):

$$\text{Organic matter (lb./day)} = 125 \times 0.833 = 104.2 \text{ pounds per day}$$

(*d*) New sludge, ash-free, dry basis (52 pct. of organic matter):

$$\text{New sludge (lb./day)} = 104.2 \times 0.52 = 54.2 \text{ pounds per day}$$

The second phase of the treatment, endogenous respiration, depends not only on the supply of oxygen but also on the total quantity of seed sludge present in the tank. Theoretically, excess-sludge disposal facilities would be unnecessary if endogenous respiration could be used to burn up the exact amount of sludge formed in the system from new waste. In practice, this means that conditions may be established to minimize excess sludge accumulation and yet retain sufficient seed for proper operation of the process.

Since it is possible to provide conditions in which the sludge will consume itself at a rate of 1 percent per hour, or about 18 percent for 20 hours of aeration, the new sludge formed is used to represent 18 percent of the seed sludge in the tank.

(*e*) Equilibrium sludge weight

$$\left(\frac{100}{18} \times \text{new sludge}\right):$$

$$\text{Total sludge (lb.)} = \frac{54.2}{0.18} = 300 \text{ pounds}$$

(*f*) Hourly oxygen requirement—

Endogenous phase (seed sludge × 1 pct. × 1.44 lb.):

$$\text{Oxygen (lb./hour)} = 300 \times 0.01 \times 1.44 = 4.32 \text{ pounds per hour}$$

Assimilation phase

$$\left(\frac{1}{8} \text{ of total for 8-hr. influent}\right):$$

$$\text{Oxygen (lb./hr.)} = \frac{46.9}{8} = 5.86 \text{ pounds per hour}$$

Total oxygen (sum of two results):

$$\text{Oxygen (lb./hr.)} = 4.32 + 5.86 = 10.18 \text{ pounds per hour}$$

This hourly oxygen requirement is needed during the assimilation of the raw waste to maintain aerobic conditions. The oxygen required during the rest of the 20-hour aeration period will be the amount needed for endogenous respiration only, 4.32 pounds per hour.

Figure 1 shows the pounds of oxygen required per hour for different amounts of waste solids treated per day over a total aeration period of 20 hours while the wastes are received for 8 hours.

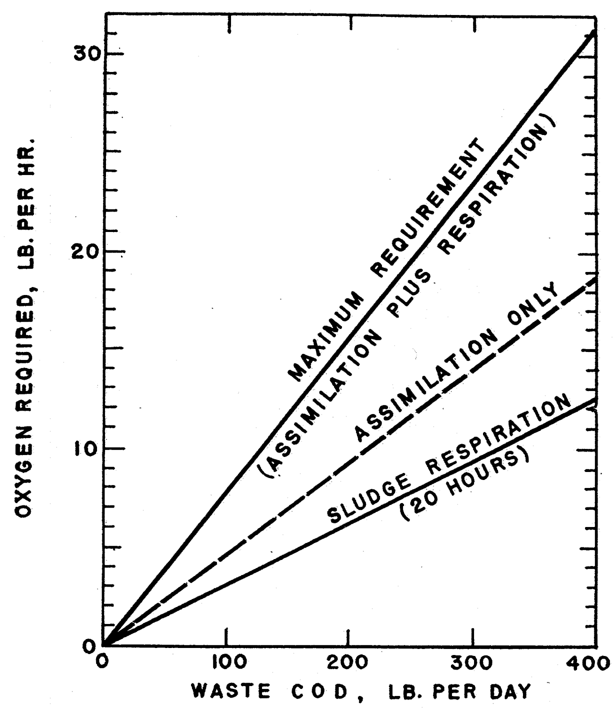

Figure 1.—Relation between waste received per day and oxygen required per hour. Waste received for 8 hours; aeration continued 20 hours.

NUMBER OF EJECTORS

To assist in rapidly determining the number of size 7A ejectors and other essential factors for a dairy waste treatment unit, the calculations have been condensed into tabular form (table 1).

The hourly oxygen requirements of the seed sludge have been added to the assimilation needs to give the maximum oxygen demand (col 7). This has been converted to the number of ejectors by dividing by the factor of 1.6 pounds per hour per ejector and rounded to the next higher unit (col. 8).

In the example treating a daily waste load of 10,000 gallons (125 pounds COD), the 10.2 pounds of oxygen can be readily supplied by 7 ejectors. The 4.3 pounds of oxygen per hour to satisfy the seed sludge can be supplied by 3 ejectors operating at full pressure. However, the same requirements can be fulfilled by using all 7 ejectors at reduced pressure. (See Appendix, p. 19.)

Table 1.—*The number of ejectors (size 7A) needed, the oxygen required, the sludge produced, and the seed sludge necessary for various waste loads in a batch operation that operates 8 hours a day*

Waste, COD	Oxygen for assimilation		New sludge	Seed sludge required	Oxygen for seed sludge	Maximum oxygen	Ejectors needed
	Total	Per hour					
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Lb./day	*Lb.*	*Lb.*	*Lb./day*	*Lb.*	*Lb./hr.*	*Lb./hr.*	*Number*
25	9. 4	1. 2	10. 9	60. 5	0. 8	2. 0	2
50	18. 8	2. 3	21. 7	120. 6	1. 6	3. 9	3
100	37. 5	4. 7	43. 4	241. 1	3. 1	7. 8	5
150	56. 3	7. 0	65. 1	361. 7	4. 6	11. 6	8
200	75. 0	9. 4	86. 8	482. 2	6. 3	15. 7	10
300	112. 5	14. 1	130. 2	723. 3	9. 4	23. 5	15
400	150. 0	18. 8	173. 6	964. 4	12. 5	31. 3	20

DESIGN OF PLANT

The information developed by following the calculations in the preceding sections should now be used to design the treatment unit. Preliminary sketches should be made to help visualize the size and location of the tank, the arrangement of ejectors, piping, pumps, and influent and effluent lines. These sketches should be developed to the point where construction costs, simplicity of operation, and maintenance costs can be estimated. Several schemes should be evaluated before the final plan is adopted.

For instance, it will be assumed that the example of 10,000 gallons is to be treated by a batch process. It has also been assumed that the two rates of oxidation are to be provided by separate pumps, one for the high rate and one for the low rate. In cases where ample area and slope of terrain are available, a design such as shown in figure 3 would fit the treatment needs. The illustration shows eight ejectors to allow for plant expansion, although only seven are needed for the example. It also contains only one pump, whereas the text recommends two. Several other details have been omitted for the sake of clarity, such as a catwalk for servicing the ejectors, safety handrails, and screens on the ejector air inlets. Conditions at the building site will frequently suggest modifications of the design shown in figure 3.

The principal aim of the waste treatment plant design is to coordinate the shape of the tank with the arrangement of the ejectors. The discharge of the ejectors should give a sweeping action to the entire contents of the tank to prevent dead pockets and to maintain the sludge in suspension. Pump inlets should be placed to avoid "short circuits" within the tank.

Other factors related to the overall design of the plant should include a consideration of materials or equipment readily available at the dairy and exclude the use of construction items difficult to procure. The designer will find the sections on "Operation of Single-Tank Batch Method," "Pumps and Piping," and "Construction" of interest. Visiting existing installations will be extremely helpful.

One practical item should not be overlooked. This is the need for screening the waste just before it enters the treatment tank to remove bottle caps, wires, or other objects that may damage the pumps or clog the ejectors. Screening should be one-fourth-inch mesh and have ample area. The screen is usually placed at the entrance to the tank adjacent to a small sump where sand and grit are settled out of the waste.

A second item that is beneficial is a small pond for receiving the treated effluent and holding it for final polishing. The pond may be stocked with fish, which will show good growth as testimony to the purity of the discharged effluent. The pond will also trap any sludge that may occasionally become entrained in the effluent.

In the case of a dairy that discharges a small quantity of waste, it is possible to use simple equipment and procedures and yet provide proper waste treatment. The plant shown in figure 4, which was designed for 5,000 gallons daily, uses four ejectors operated by a single pump. Here economy of construction and simplicity of operation led to the choice of a single pump with a 10-horsepower motor, which is adequate for assimilation. The same pump is used during endogenous respiration, because a two-pump

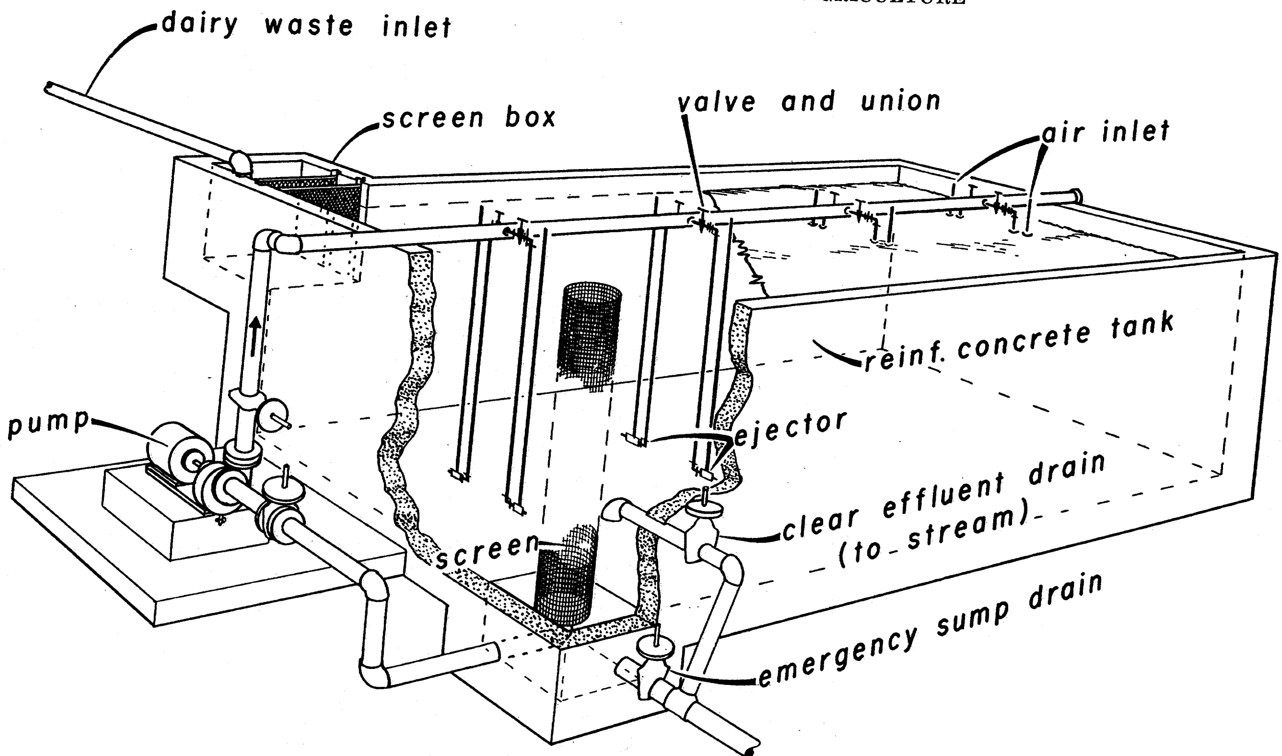

FIGURE 3.—Typical batch-type dairy waste treatment plant.

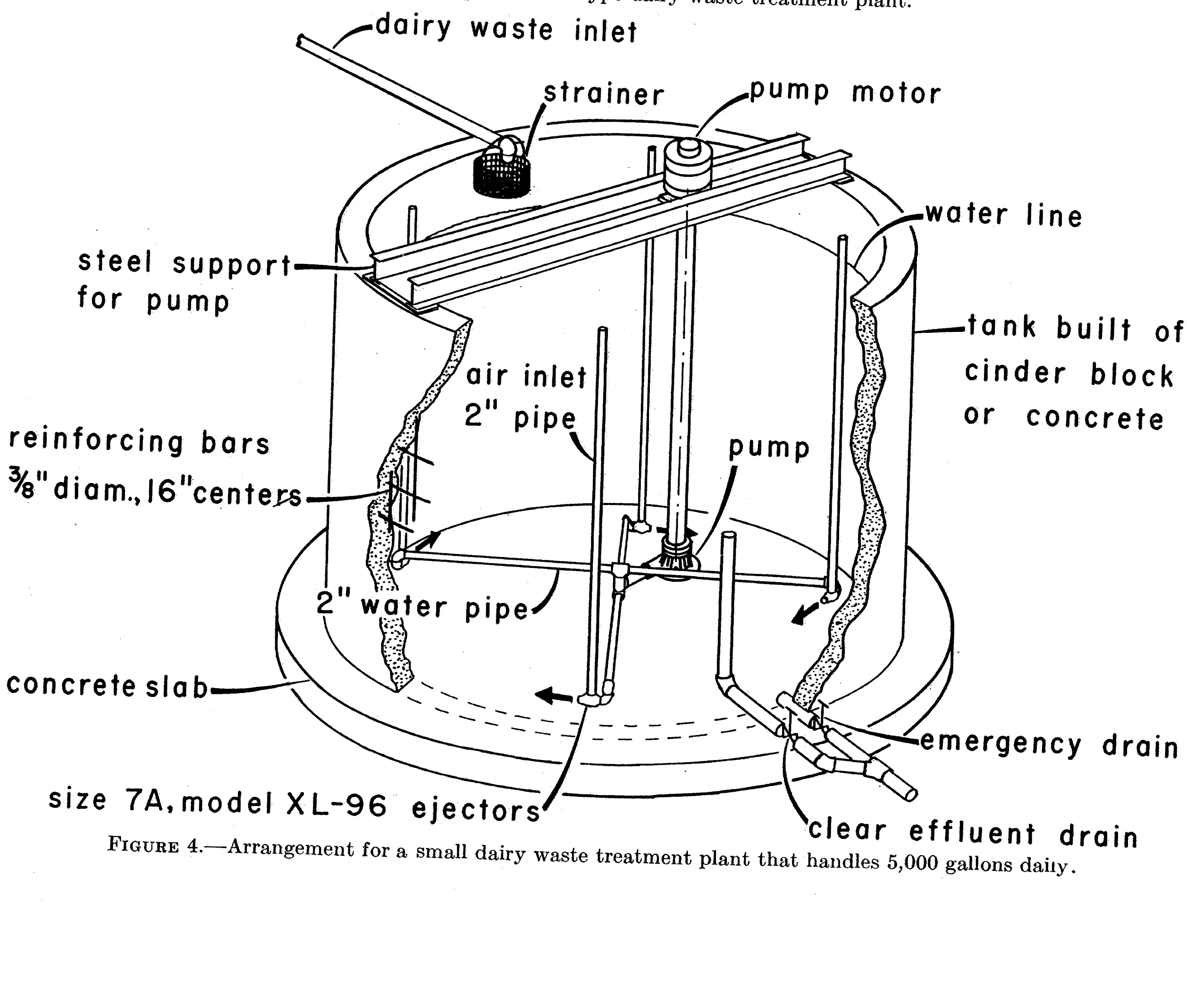

FIGURE 4.—Arrangement for a small dairy waste treatment plant that handles 5,000 gallons daily.

system would have been more expensive to install. The simplicity of this design, however, has led to difficulty in maintaining the ejectors and pump, since repairs must be made after draining the tank. The arrangement would be better if, along with other improvements, a hoist could be provided to lift the pump and ejectors clear of the tank.

In larger aeration units, it is desirable to use at least two pumps. One pump can be in continual operation and supply the relatively small quantity of air required for sludge burnup. The second pump would also be running during assimilation, so that the two pumps together would provide the maximum amount of oxygen. Or the second pump may be used to furnish the entire amount of air needed during the assimilation phase.

In the disposal unit shown in figure 5, two pumps each deliver 900 gallons of liquid per minute for the assimilation phase. Then for the endogenous phase, only one pump is used to supply the 24 ejectors by means of the cross-connection at the far end of the manifolds. This is shown on the right in figure 5.

Another detail of interest in this figure is the design of the two cylindrical screens that protect the pump suction. The extension of the top of these screens to a level higher than the waterline not only increases their area but makes them easy to inspect and clean.

The protection of the air intakes for the ejectors at this treatment plant should also be mentioned. The location of each ejector can be identified by the two pipes connected to it (fig. 5). One pipe is connected to the larger pipe manifold; this is the liquid connection to the ejector. The other pipe of each group of two connects the air intake of the submerged ejector with the atmosphere. The entrance of these air intakes is filled with a screen of one-half-inch mesh hardware cloth. The suction created here is powerful enough to draw small birds, leaves, and other debris into the pipe and to cause clogging of the piping or ejectors. The notch in the cinderblock wall at the far side of the tank is used to control accidental flooding by directing the overflow into a small lagoon.

Not discernible in the photograph is the healthy color of the aerated sludge and waste. A properly operating plant will usually develop a light-brown or pinkish-colored sludge.

OPERATION OF SINGLE-TANK BATCH METHOD

The operation of a treatment plant can be quite simple when the equipment and sludge bed are in good condition. As the waste from the dairy begins to enter the tank, the full aeration system is turned on. To insure that all fresh organic matter is assimilated, aeration continues while the waste is being received and for an additional hour or two. When the waste has been assimilated, the pump is shut off, and the sludge is allowed to settle. In a normally operating treatment unit, settling is usually complete within 2 hours. The clarified water above the sludge can then be discharged through the clear effluent drain. In the drawing in figure 2, this drain was placed 2.9 feet above the tank bottom, or 2 feet above the settled layer of sludge. After draining has been completed, the drain valve is closed. The aeration system is again started and run for the remainder of the 24 hours at a rate adequate for endogenous respiration. The cycle of daily operation is again initiated at the start of the next workday by raising the aeration rate to full capacity as soon as wastes enter from the dairy.

It can be seen from the above outline that a normally operating plant would require only four short periods of attention. It is suggested that the cost of automatic operation for all or part of the system be investigated.

In starting a new waste treatment plant, time is required to accumulate the calculated equilibrium sludge quantity. A severe lack of seed sludge will slow down the assimilation rate, making longer aeration necessary. Some operators have added a quantity of sludge from another aeration system or washings from a rich garden soil to accelerate sludge buildup. This is probably unnecessary, because the average treatment system offers excellent food and environment for bacterial multiplication.

Some control can be exercised over the size of the seedbed by varying the time and rate of aeration for endogenous respiration. The success of the treatment, however, depends on providing the correct environment for the sludge. Careful measurements in the pilot plant verified the possibility of a rate as high as 1.25 percent per hour for seed sludge burnup. Average conditions easily produced a burnup rate of 1 percent per hour. Reports of plants in operation tell of total daily rates as low as 5 percent and as high as 25 percent. A type of treatment described as total oxidation is based entirely on successful endogenous respiration (*15*, *21*).

If excessive sludge accumulates in the system despite the operator's efforts, it will require removal. As the sludge from this type system is well aerated, it is practically odorless, but because it is a mixture of bacterial cells, some care should be exercised in its disposal. In its diluted state, the sludge may be readily pumped and safely spread on an uncultivated field. In a solid or semisolid state, it is more difficult to handle, but can be transported, dried, and disposed of by methods similar to those used in municipal plants.

FIGURE 5.—A 35,000-gallon batch treatment unit in operation. The edge of the pump house is at the left.

If insufficient sludge is present and less aeration is needed, it is suggested that a program of short aeration periods alternating with long resting periods be followed. Sludge in good condition can rest 6 hours without deleterious effects if it is then aerated for approximately ½ hour. It is not known how much longer sludge in this type system can remain aerobic without a fresh oxygen supply.

Operating difficulties will eventually be encountered as with all mechanical contraptions. Pump impellers and ejector water jets will show signs of wear when the waste contains much gritty material. Measuring the velocity of the air flowing into the ejector intakes can be used as a check on the performance of the ejectors and pumps. Precise measurement in terms of the volume of air is not so important in this case as employing a measuring device that will give repeatable results with which later measurements can be compared. When low entrance-air velocity is discovered, the cause should be investigated and corrected if the plant is to be kept in top condition.

The correction of other difficulties, such as excessive foaming and low temperature wastes, have been discussed in separate sections.

USE OF AIR UNDER PRESSURE

When the quantity or strength of waste is high, it may be advantageous to supply air under slight pressure to assist the ejectors. A fewer number of ejectors and a smaller recirculating pump would then be needed. The study showed that when compressed air was supplied to the air intake of the ejector (size 7A) at 6 pounds per square inch, the rate of dissolving oxygen was increased by 50 percent. Under such conditions, even though more oxygen was forced into solution, the efficiency of the ejector is not so high as when it is drawing air at atmospheric pressure. The quantity of air passing through the device was doubled in order to dissolve 50 percent more oxygen. Further increases in air pressure gave insignificant increase in oxygen-dissolving ability.

By using air under pressure, the increased oxygen-dissolving capacity of ejectors may be used to improve existing plants where dairy operations have expanded and treatment for additional waste is needed.

CONTINUOUS-PROCESS TREATMENT PLANT

The biological principles of continuous treatment are identical with those of a batch process, but the continuous process poses design problems not encountered in batch treatment (*5*). These include necessary settling space and time to give a clear effluent; sufficient aeration for proper assimilation; space for endogenous respiration; and means of returning seed sludge to the assimilation area. Each problem must be successfully solved for the continuous treatment plant to work satisfactorily. Figure 6 presents a schematic diagram in which air is supplied under pressure for a theoretical continuous process. If a continuous-process treatment plant is contemplated, a competent sanitary engineer should be employed who understands the biochemistry of milk waste disposal.

Many arrangements have been used for continuous-flow milk waste treatment. One type combines all aeration with flow equalization in the first tank. A second tank is used for settling. This type of operation returns all sludge to the first tank, and flow rates are adjusted to provide for assimilation and sludge burnup concurrently (*9*). Variations of this arrangement have used a separate flow equalization tank, or provided for occasional or regular sludge removal. Where the treatment plant depended on regular removal, the sludge was directed to a sandbed or digester or was spread on a field. A different treatment approach is mentioned (*5*), wherein the sludge is separated from the water immediately after assimilation and is oxidized in the form of a concentrate.

Theoretically, the ideal system provides adequate sludge for rapid assimilation, limits the quantity to be settled, and provides sufficient return sludge for endogenous respiration to destroy the exact weight of sludge produced from the incoming waste. Removal of excess sludge would be minimized, and yet an adequate seeding would be assured. The following general discussion shows steps in designing a unit.

Again, the first step is to know the quantity of waste and its concentration. In order to give a concrete example, a rate of flow of 1,200 gallons per hour and a concentration of 1,600 p.p.m. COD will be assumed.

(*a*) Total oxygen required:

Total oxygen (lb.)

$$=\frac{1{,}200 \text{ gal./hr.} \times 8.34 \text{ lb./gal.} \times 1{,}600 \text{ p.p.m.}}{1{,}000{,}000}$$

$=16$ pounds oxygen per hour

Following the example of batch treatment calculations, it will be seen that 6 pounds per hour (37.5 percent) of oxygen are needed for assimilation. This can be supplied by 4 ejectors, each dissolving 1.6 pounds of oxygen per hour.

The problem of endogenous respiration can yield

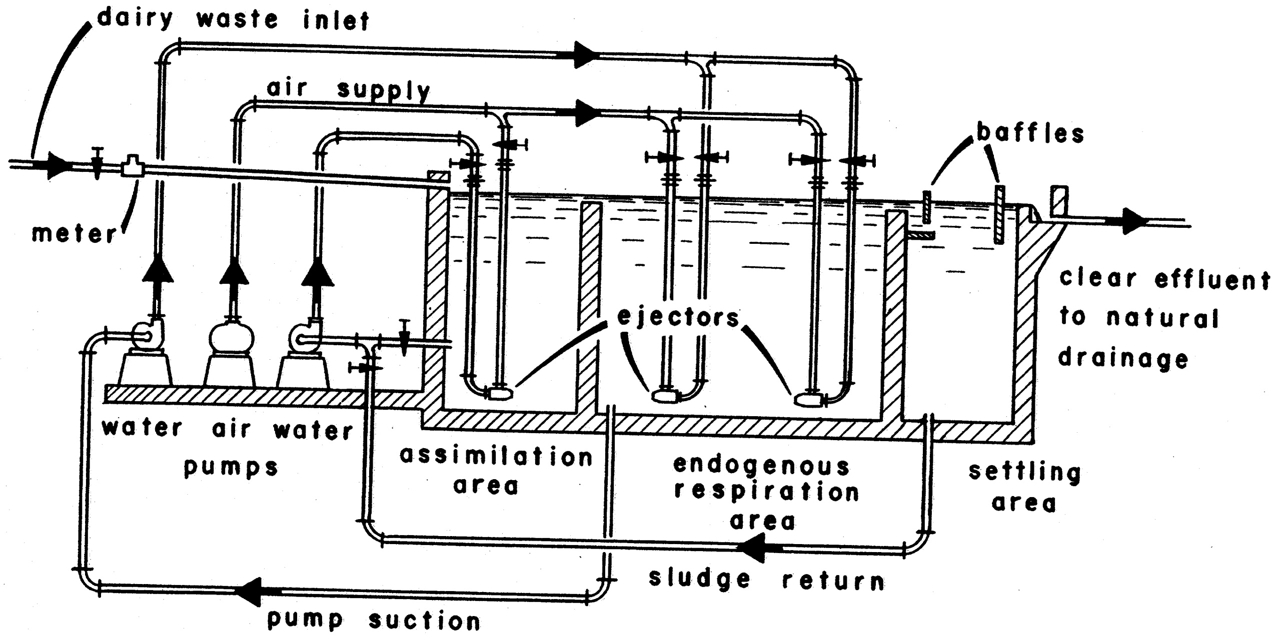

FIGURE 6.—Schematic diagram of continuous-process dairy waste treatment.

to a wide latitude of treatment plant designs. Where space is limited, the tank area for endogenous respiration may be made quite small by selecting a short retention time. In such cases, an enormous quantity of seed sludge must be continually settled, returned, and mixed with the influent. The limiting factors for long periods of retention are the large tank size and insufficient sludge to satisfy rapid assimilation. (See par. (5), p. 2.)

To select a reasonable retention time, the new sludge production must be known. The hourly production of sludge is obtained by taking 52 percent of the incoming waste solids (equal to the total COD divided by 1.2).

(*b*) NEW SLUDGE:

$$\text{New sludge (lb./hr.)} = \frac{16 \times 0.52}{1.2}$$

$$= 6.92 \text{ pounds sludge per hour}$$

The period of retention will undoubtedly be governed by local circumstances and the personal preference of the designer. The calculations will be here demonstrated for 12 hours. At the established rate of 1 percent per hour, 12-hour retention will consume approximately 10 percent of the seed sludge, which means that 10 times the weight of sludge to be oxidized must be present at the entrance. The minimum quantity of sludge to be settled and returned to the entrance of the endogenous area will be the difference between the total required and the new sludge production.

(*c*) RETURNED SLUDGE (total sludge—new sludge):

$$\text{Returned sludge (lb./hr.)} = 69.2 - 6.9$$

$$= 62.3 \text{ pounds per hour}$$

The volume of this sludge will not be subject to exact prediction because of variation in nature of the sludge and the operation of the settling tank. Equipment for returning sludge to the head of the endogenous chamber should handle at least double the "well-settled" volume (see par. (8) p. 2) of this amount of sludge.

Air requirements for the endogenous phase may be calculated in the same way as for a batch treatment unit. In the continuous operation plant, however, some excess air should be provided to insure that the sludge is well aerated when it enters the settlement tank.

(*d*) OXYGEN FOR SLUDGE BURNUP (total sludge weight $\times$ 1 pct. per hr. $\times$ 1.44):

$$\text{Oxygen (lb./hr.)} = 69.2 \times 0.01 \times 1.44$$

$$= 0.996 \text{ pound per hour}$$

In this example it was shown above that the immediate assimilation of waste required 6 pounds of oxygen per hour. To this figure is added the oxygen needed for burning up the recirculating sludge at a rate producing equilibrium. The total requirement then is 7 pounds per hour.

Two properties of the continuous system should be pointed out. The controlled return of a large amount of sludge makes the assimilation of a new waste material practically instantaneous; as a result, a separate tank for this phase is unnecessary. The second property of the process is that the endogenous activity of sludge continues during settlement. The rate of activity may not be as high as 1 percent per hour, since no aeration is used during settlement.

The remaining step in the continuous treatment is that of clarification of the effluent in a settling chamber. Design of this chamber may be based on measurements taken during the experimental studies, which showed that bacterial cells from milk waste settled at a rate of 2 to 8 feet per hour, depending on the concentration. This is equal to a surface loading of 15 to 60 gallons per hour per square foot of surface (360 to 1,440 gallons per day per square foot). An empirical formula was developed from the pilot plant data relating the settling rate (R, as feet per hour) with the sludge cell concentration (parts per million).

$$R=\frac{10{,}240-\text{p.p.m.}}{950} \qquad (2)$$

The sludge concentration in the continuous process example is calculated in parts per million from the weight of sludge divided by the weight of liquid entering the settling tank on an hourly basis according to the following formula:

$$\text{Concentration (p.p.m.)}=\frac{A\times 1{,}000{,}000}{(B+C)\times 8.34} \qquad (3)$$

A=weight of sludge (lb.)

B=influent volume (gal.)

C=return sludge volume (gal.)

(weight of sludge, lb.×6 gal./lb.)

(*e*) Sludge concentration (by formula 3):

$$\text{Concentration (p.p.m.)}=\frac{62.3\times 1{,}000{,}000}{(1{,}200+374)\times 8.34}$$

$$=4{,}746 \text{ parts per million}$$

In this example the theoretical figure for return sludge volume has been given. In practice, the capacity of the sludge return equipment should be used.

(*f*) Settling rate (by formula 2):

$$R=\frac{10{,}240-4{,}746}{950}$$

$$=5.8 \text{ feet per hour}$$

$$=43.35 \text{ gallons per hour per square foot}$$

(*g*) Settling area (total gallons÷rate):

$$\text{Area (sq. ft.)}=\frac{1{,}200+375}{43.35}$$

$$=36.33 \text{ square feet}$$

This is the theoretically correct value, subject to increase by the engineer in light of his experience with settlement tanks.

Attention must also be given to the inlet and outlet of the settlement basin. The velocity of the liquid at the entrance must not exceed 1 foot per second, or the liquid will have a tendency to remain in a solid stream, disturb the settling, and cause turbulence in the chamber.

At the outlet of the settlement basin the usual practice is to provide a baffle under which all water must flow, then a weir over which the clear water flows into a trough for collecting and discharging. The present accepted practice in the design of outlet weirs is to limit the discharge to 5 gallons per minute (or 300 gallons per hour) for each foot of weir length. The rate of overflow will be the same as the rate at which the waste enters the treatment plant, and, in this case, will require 4 lineal feet of overflow weir. Many designers retard the liquid movement at the entrance and exit by means of baffles, divider partitions, or piping, but areas occupied by these devices should not be considered part of the settling area.

One further detail is necessary. In the experimental work, cells forming the sludge have a tendency to cling together and become difficult to move once they become compacted. For this reason, some mechanical means should be provided to scrape the sludge slowly toward the sludge return pump suction if the settling tank has a flat bottom.

PUMPS AND PIPING

As the waste treatment system will be an essential and continuing part of dairy plant operations, reliability is a most important factor to consider when planning the system. For instance, the pumping requirements may be provided by using two pumps. This may not be feasible for a small system, but a spare pump is desirable. The plans may provide for the future addition of a second pump by the proper placement of tees or other fittings. After a year or two of operation, a review of the waste treatment program may show that a somewhat larger capacity is needed. At this time, a larger pump may be installed and the original pump reserved as a spare. The new pump may be designed to operate the same size and number of ejectors at a higher operating pressure and higher rate of flow, in order to satisfy the increased oxygen requirements. Other alternatives may be to use the new pump for the assimilation phase and the old pump for the endogenous phase; or the two pumps may be used together for assimilation, with only one used for the endogenous phase.

The first step in selecting a pump is to sketch out a piping diagram, such as figure 7, to fit the size and shape of the tank that has been selected. Figure 7 provides branches for 8 ejectors instead of the 7 calculated to be necessary for the 10,000-gallon example. This illustrates the suggestion that the original layout should provide definite steps for future expansion.

A good pipe layout is as simple and direct as possible. It provides a system that may be completely drained, and it has enough valves for isolation of any unit that may need repairs while the rest of the system continues to operate. Unions on small pipes and bolted flanges on larger pipes should also be used to facilitate necessary repairs.

Once the general idea of the piping is sketched, showing the proposed dimensions, sizes, and flows, the frictional pressure losses are determined. This is done with the aid of information and tables usually found in the general catalog of plumbing supply companies or in standard engineering handbooks. Calculations need be made only for the ejector that is farthest from the pump.

A summary of typical pipe friction losses is given in table 2, based on the arrangement shown in figure 7, for the treatment plant. The fittings have been converted to equivalent lengths of straight pipe, using the factors from the chart in the catalog of Crane and Company (*4*). Velocities and losses per 100 feet are from the same source. The equivalent length method is suggested because it is widely available and easy to follow. For the more exact determination of pressure losses in large complicated systems, it is recommended that the method using losses as a percentage of velocity pressure be followed. This is available in standard mechanical engineering texts. The resistance to flow is the sum of all the effects in the series of pipes, fittings, and devices that the pump must overcome in the system to produce the desired flow

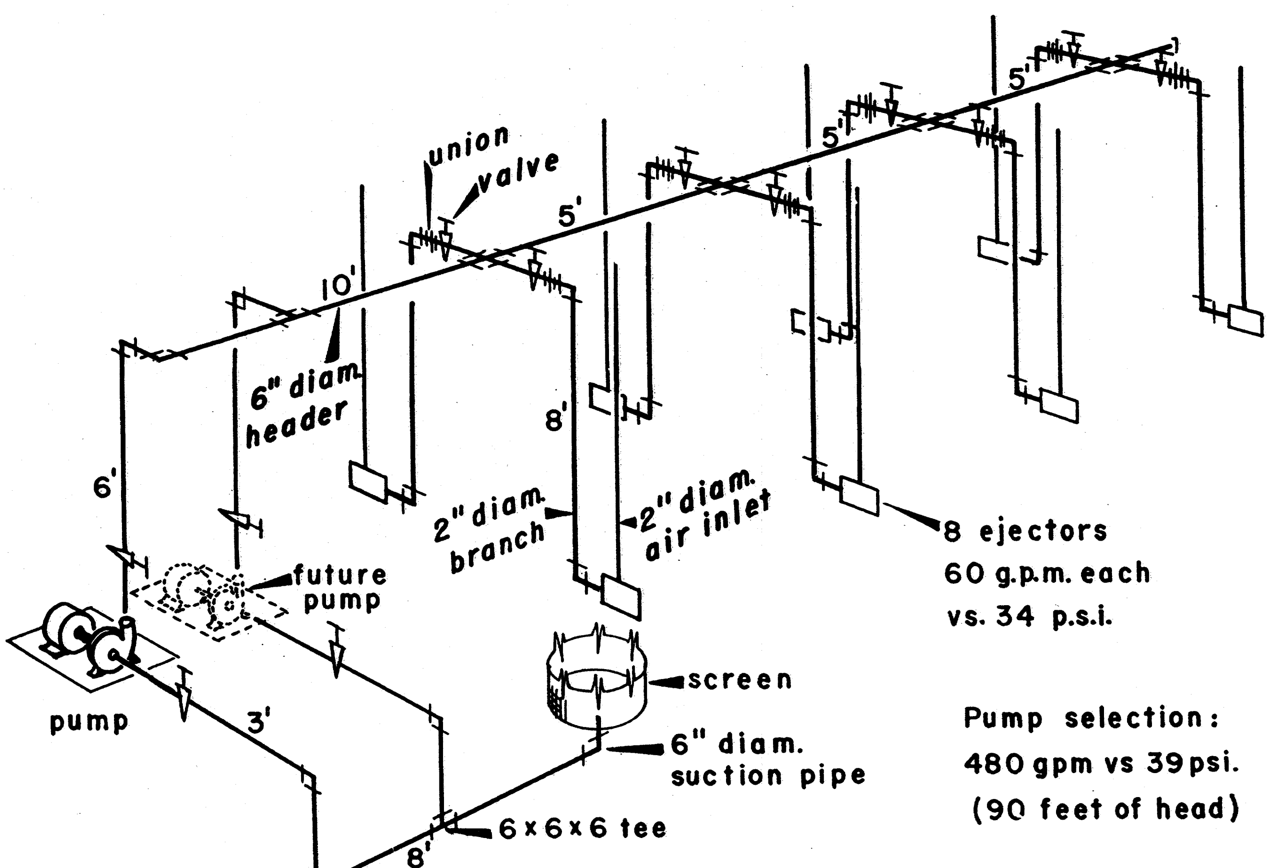

FIGURE 7.—Sketch of piping diagram for a treatment plant to handle 10,000 gallons of waste per day.

TABLE 2.—*Calculation of pipe friction for a plant handling 10,000 gallons of dairy waste per day*

Description	Flow	Velocity	Equivalent length		Pressure losses		
			Part	Total	Per 100 feet	Per item	Total [1]
Suction piping	*G.p.m.*	*Ft./sec.*	*Feet*	*Feet*	*P.s.i.*	*P.s.i.*	*P.s.i.*
Entrance loss (abrupt)	480	5. 3	9	9	0. 66	0. 059	0. 059
6-inch pipe, 14 feet long	480	5. 3	14				
Elbows, 3, total	480	5. 3	48				
Valve, open	480	5. 3	4	78	. 66	. 515	. 574
Tee, run	480	5. 3	12				
Discharge piping							
4-inch pipe nipple	480	12. 0	1				
4-inch gate valve, open	480	12. 0	2	6	5. 17	. 310	. 310
4 x 6 increaser	480	12. 0	3				
6-inch pipe, 17 feet long	480	5. 3	17				
6-inch elbows, 2, total	480	5. 3	32	61	. 66	. 403	. 713
6-inch run of tee	480	5. 3	12				
6-inch pipe, 5 feet long	360	4. 3	5				
Cross	360	4. 3	12	17	. 384	. 065	. 778
6-inch pipe, 5 feet long	240	2. 6	5				
Cross	240	2. 6	12	17	. 182	. 031	. 809
6-inch pipe, 5 feet long	120	1. 3	5				
Cross	120	1. 3	12	17	. 036	. 006	. 815
2-inch side outlet, cross	60	5. 7	12				
2-inch pipe, 10 feet long	60	5. 7	10				
2-inch els, 2, total	60	5. 7	6	30	2. 96	. 888	1. 703
2-inch gate valve, open	60	5. 7	2				

[1] Discharge, total 1. 703
Suction, total 574

Pressure used at ejector 2. 277
34. 0

Total pumping head, p.s.i 36. 277
Feet of head=36.277×2.311=83.84 feet.

of liquid through the last ejector. As the routes to the other ejectors are shorter, they offer slightly less resistance. During operation, slight throttling at the 2-inch valves in the lines to the ejectors with shorter runs may be necessary if perfect balance of output is to be achieved.

Once the frictional losses are determined and the design of the system is found satisfactory, the pump is selected. With each of the size 7A ejectors delivering 60 gallons of flow per minute at 34 pounds per square inch pressure at the nozzle, the pump selected from data obtained in table 2 should delivery 480 gallons per minute against a head of 90 feet. Preferably, it should be a ball-bearing type with a speed of not more than 1,750 r.p.m. It should be a double-suction type with a stainless steel shaft and split glands, if it is to have a long life and be easy to maintain. The pump should also be set low enough to keep the suction piping flooded at all times. Further details, advantages, and economies of pump selection should be discussed with the representative of the pump manufacturer.

One thing should be categorically stated: the electric motor driving the pump should be guaranteed not to be overloaded under normal operating conditions. Good pump and motor installation requires that the electric motors be operated at the highest usable voltage at the plant, be properly protected by overload devices, and that 3-phase current be used on motors of 1 horsepower or larger. The motors should be rated for continuous duty and preferably be totally enclosed.

CONSTRUCTION OF TREATMENT PLANT

A desirable site for the treatment plant must be selected and surveyed to assure enough difference of elevation from the dairy to the treatment plant and from the treatment plant to the receiving stream. Most State regulations require a minimum fall in drain piping of 0.4 foot per 100 feet. If sufficient drop to the tank from the drain outlet is not available for gravity drainage, the waste can run into a sump pit and be pumped into the treatment tank.

The cylindrical tank shown in figure 4 for handling 5,000 gallons of waste may be constructed economically of cinder-concrete blocks. It would be desirable, though not necessary, to allow 6 feet of the tank to be below ground with about 3 feet above ground. This would provide lateral support, allow for easy observation of the tank contents, provide insulation against low temperatures, permit ready cleaning of the inlet strainer, allow accessibility to the effluent drain, and create less difficulty in raising the motor.

Specifications for such a cinder-block tank should give finished dimensions and type of reinforcing, define mortar used (2½ parts sand; 1 part cement; no lime), and require cement dashing and hot asphalt waterproofing on the inside surfaces. Workmanship, material for electric wiring, plumbing, and any special conditions should also be specified. Attention must be given to details of good construction. Those outlined here may not apply to tanks of other sizes or shapes, but are included to indicate that a high level of workmanship quality should be incorporated in building the system to provide a long trouble-free life.

The base slab of concrete should extend beyond the walls of the tank to serve as a footing. A concrete slab that has a wall resting on its edge should be reinforced. The round tank selected as an example would have a bottom slab 7 inches thick and be strengthened with reinforcing bars, ½ inch in diameter, placed 6 inches on centers. Two complete sets of bars would be installed perpendicular to each other and protected by 3 inches of concrete above, below, and at the edge.

In constructing tank walls, the pressure of liquid must be taken into consideration. The greatest pressure on the finished wall is at the bottom; hence, vertical bars for the walls must be well anchored in the base slab. The use of separate pieces of rod 4 feet long, bent at right angles in the middle, is recommended. These are wired to the slab reinforcing before the slab is poured, with half the bar placed upright at the correct location to fit the cinder-block courses. The vertical rods for the wall are securely wired to the short rods with a 15-inch lap. Although many details concerning concrete are found in the "Building Code Requirements for Reinforced Concrete" (*1*), expert engineering advice should be obtained for all but the simplest structures.

The wall should be as heavy as possible to assure the greatest stability when subjected to varying horizontal pressures as in a dairy waste treatment tank. Weight is provided by using as many solid cement blocks as possible in constructing the tank. Alternate courses could be made of solid and hollow blocks. The vertical rods may pass between the ends of solid blocks in one set of courses and through the center of hollow blocks on the alternate courses, which are then filled with well-tamped mortar. Filling the cells bonds the rods and cement work together and adds to the stability of the wall by making it heavier.

Rectangular tanks may also be built of cinder-concrete blocks, if ample buttressing is provided. Thus, a typical block wall, 8 inches thick, may be used if distances between buttresses or piers are short; i.e., not over 10 feet. Piers must be heavy and the wall must be well reinforced to withstand the water pressure acting horizontally when the tank is full and the earth pressure when the tank is empty.

Flexibility must be provided at the joints where pipes pass through the wall of the tank. A separate sleeve of cast iron or asbestos-cement pipe should be placed in the wall as the masonry is laid. This should allow at least one-fourth inch all around the future pipe to be installed. After the wall is waterproofed, the piping is installed through the sleeve and packed with oakum and flexible calking compound.

COST ESTIMATES

Costs of installing dairy waste treatment plants vary widely. Installation of the rapid-aeration units have cost about one-third of the more elaborate multiple-unit methods of waste treatment (*23*). Tanks and equipment available at the site have also been used to reduce the cost of small units.

The batch process, in which a single tank is used for the entire process, is the least costly. If the dairy is in operation 15 hours or longer, continuous sedimentation is necessary and an additional tank or a separate compartment in the same tank is needed. A chlorinator may be needed if disinfection is required by the health authorities. The following construction cost items are to be considered: (1) Land for the treatment plant; (2) property easements for sewer lines; (3) electrical power line; (4) pumping station; (5) excavation; (6) tank construction; (7) pump, ejectors, and piping; and, if needed, (8) sedimentation tank and (9) disinfection tank. If sufficient land with suitable slope is on hand, then the bare minimum for cost will be that for electric power lines, tank construction, pump, ejectors, and piping, including the repiping of nonpolluted waters.

In 1959, the method for the treatment or disposal of milk wastes had not been standardized. In 1953, a 5-year appraisal of 20 milk products plants reported wide differences in methods of treatment (*23*). Some plants took advantage of municipal sewerage systems and paid rental charges that amounted to 0.02 to 0.11 cents per quart of milk handled. In some cases, additional expenditures for pretreatment were required. Two elaborate waste-treatment plants using trickling filters were described later (*24*). One was constructed at a cost of $100,000 to treat 500 pounds of BOD daily and operated at an annual cost of $4,000. Construction costs of the second plant, treating 325 pounds of BOD, was $70,000 with an annual operating cost of $2,500.

Several small milk-waste disposal plants of varied design are in use (*9*). A simple one-tank batch method (*12*) of 25,000-gallon capacity treats 220 pounds of BOD daily and cost $6,000 in 1954, according to the owner. The engineering estimate on this plant was $14,000, but the owner used existing equipment and plant personnel on the installation and thus effected savings. An estimate made at the same time for a dairy receiving 150,000 pounds of milk per day was $11,000 for installation of a treatment plant, and power costs were estimated at $16 per day for the unit.

These 1954 estimates represented minimal costs at that time and may not have included cost of land, easement rights, and engineering. Estimates for 1960 will undoubtedly be higher and will vary according to local costs of labor and materials. The 1954 estimates calculate to $70 to $80 per pound of BOD treated daily, but actual construction costs of $140 per pound of BOD were found to be the case in the north-central area of this country the same year.

Although the cost of construction generally increases with the size of the plant, the cost per pound of waste to be treated shows a decrease. In very small plants the cost is not proportional to the smaller quantity of milk handled. A greater allowance is usually made for future expansion in the small plant, and thus the treatment plant may be twice the size necessary for immediate needs. This may make the initial construction cost high.

CONCLUSIONS

Treatment of dairy waste is being recognized as an integral part of dairy plant operation. Disposal of dairy waste by aerobic treatment must follow recognized principles and proven practices. Treatment costs money. Good housekeeping and elimination of wasteful practices will reduce the waste and reduce the cost of treatment. This handbook gives facts, figures, and suggestions that the plant operator and the sanitary engineer can use. Aeration units that are in operation should be visited before designing a new plant. The dairy plant operator should check on the work of the engineer, know the equipment, and adequately understand the operation of the treatment plant. He should also be familiar with the requirements of the local sanitation code.

LITERATURE CITED

(1) AMERICAN CONCRETE INSTITUTE COMMITTEE 318.
1956. BUILDING CODE REQUIREMENTS FOR REINFORCED CONCRETE (ACI–318–56). Amer. Inst. Jour. 27 (Proc. 52): 913–986, illus. (Title 52–57).

(2) AMERICAN PUBLIC HEALTH ASSOCIATION, INC.
1955. STANDARD METHODS FOR THE EXAMINATION OF WATER SEWAGE AND INDUSTRIAL WASTES. Ed. 10. Waverley Press. Baltimore, Md.

(3) CORMAN, J., TSUCHIYA, H. M., KOEPSELL, H. J., and others.
1957. OXYGEN ABSORPTION RATES IN LABORATORY AND PILOT PLANT EQUIPMENT. Appl. Microbiol. 5: 313–318, illus.

(4) CRANE AND COMPANY.
1949. VALVES, FITTINGS, PIPE, LUBRICATED PIPING. Catalog 49.

(5) ECKENFELDER, W. W., JR., and O'CONNOR, D. J.
1959. BIO-OXIDATION OF ORGANIC WASTES—THEORY AND DESIGN. Civil Engin. Dept., Manhattan College, N. Y. 127 pp., illus.

(6) HOOVER, S. R., JASEWICZ, L., and PORGES, N.
1952. BIOCHEMICAL OXIDATION OF DAIRY WASTES. IV. ENDOGENOUS RESPIRATION AND STABILITY OF AERATED DAIRY-WASTE SLUDGE. Sewage and Indus. Wastes 24: 1144–1149.

(7) ——— JASEWICZ, L., and PORGES, N.
1954. BIOCHEMICAL OXIDATION OF DAIRY WASTES. VI. RELATIONSHIP BETWEEN THE RATE OF PURIFICATION AND RATE OF OXIDATION AND GRAPHICAL ESTIMATION OF FIRST ORDER VELOCITY CONSTANTS. Purdue Univ. Indus. Waste Conf. Proc. 9: 71–79.

(8) ——— and PORGES, N.
1952. ASSIMILATION OF DAIRY WASTES BY ACTIVATED SLUDGE. II. THE EQUATION OF SYNTHESIS AND RATE OF OXYGEN UTILIZATION. Sewage and Indus. Wastes 24: 306–312.

(9) HORTON, J. P., and TREBLER, H. A.
1953. RECENT DEVELOPMENTS IN DESIGN OF SMALL MILK WASTE DISPOSAL PLANTS. Sewage and Indus. Wastes 25: 941–949.

(10) JASEWICZ, L., and PORGES, N.
1958. AERATION OF WHEY WASTES. I. NITROGEN SUPPLEMENTATION AND SLUDGE OXIDATION. Sewage and Indus. Wastes 30: 555–561.

(11) KOUNTZ, R. R.
1953. DAIRY WASTE TREATMENT PILOT PLANT. Purdue Univ. Indus. Waste Conf. Proc. 8: 382–386.

(12) ———
1954. BIG PROBLEM: DAIRY WASTES. STRIKING SOLUTION: BIO-OXIDATION. Food Engin. 26: 89–90.

(13) ———
1956. EVALUATING PROPRIETARY AERATION DEVICES. *In* Biological Treatment of Sewage and Industrial Waste. Aerobic Oxidation. (McCabe and Eckenfelder, eds.). v. 1, pp. 212–214. Reinhold Publ. Corp., N. Y.

(14) ——— and FORNEY, C., JR.
1958. ACTIVATED SLUDGE TOTAL OXIDATION METABOLISM. Purdue Univ. Indus. Waste Conf. Proc. 13: 313–320.

(15) McKinney, R. E., Symons, J. M., Shifrin, W. G., and Vezina, M.
1958. DESIGN AND OPERATION OF A COMPLETE MIXING ACTIVATED SLUDGE SYSTEM. Sewage and Indus. Wastes 30: 287–295.

(16) Milk Industry Foundation.
1957. MANUAL FOR MILK OPERATORS. Ed. 2. 686 pp., illus. Washington, D.C.

(17) Porges, N.
1956. WASTE TREATMENT BY OPTIMAL AERATION-THEORY AND PRACTICE IN DAIRY WASTE DISPOSAL. Milk and Food Technol. Jour. 19: 34–38.

(18) ——— Jasewicz, L., and Hoover, S. R.
1956. SIMPLE METHOD FOR ESTIMATING OXYGEN VALUE OF WASTES. Indus. Wastes 1: 95–98.

(19) ——— Pepinsky, J. B., Hendler, N. C., and Hoover, S. R.
1950. BIOCHEMICAL OXIDATION OF DAIRY WASTES. I. METHODS OF STUDY. Sewage and Indus. Wastes 22: 318–325.

(20) Powers, T. J.
1949. TREATING SEWAGE. (U.S. Patent No. 2,479,403.) (Aug. 16, 1949).

(21) Tapleshay, J. A.
1958. TOTAL OXIDATION OF ORGANIC WASTES. Sewage and Indus. Wastes 30: 652–661, illus.

(22) Trebler, H. A., and Harding, H. G.
1955. EXPERIENCES AND QUESTIONS CONCERNING AERATION METHODS AS APPLIED TO DAIRY WASTES. Purdue Univ. Indus. Waste Conf. Proc. 10: 1–13.

(23) Zack, S. I.
1953. TREATMENT AND DISPOSAL OF MILK WASTES. Sewage and Indus. Wastes 25: 177–187, illus.

(24) ———
1956. TRICKLING FILTER TREATMENT OF WASTES AT TWO MILK PROCESSING PLANTS. Sewage and Indus. Wastes 28: 1009–1019.

EURDD PUBLICATIONS

The following publications were published in the course of laboratory and pilot plant investigations on the biological oxidation of dairy waste by the Eastern Utilization Research and Development Division.

1949

Hoover, S. R., and Porges, N.
TREATMENT OF DAIRY WASTE BY AERATION. II. CONTINUOUS AERATION STUDIES. Purdue Univ. Indus. Waste Conf. Proc. 5: 137–144.

Porges, N., and Hoover, S. R.
TREATMENT OF DAIRY WASTE BY AERATION. I. METHODS OF STUDY. Purdue Univ. Indus. Waste Conf. Proc. 5: 130–136.

1950

Porges, N., Pepinsky, J. B., Hendler, N. C., and Hoover, S. R.
BIOCHEMICAL OXIDATION OF DAIRY WASTES. I. METHODS OF STUDY. Sewage and Indus. Wastes 22: 318–325, illus.

——— Pepinsky, J. B., Hendler, N. C., and Hoover, S. R.
BIOCHEMICAL OXIDATION OF DAIRY WASTES. II. COMPARATIVE STUDY OF YEASTS. Sewage and Indus. Wastes 22: 888–892, illus.

1951

Hoover, S. R., Jasewicz, L., Pepinsky, J. B., and Porges, N.
ASSIMILATION OF DAIRY WASTE BY ACTIVATED SLUDGE. Sewage and Indus. Wastes 23: 167–173.

——— Jasewicz, L. B., and Porges, N.
VITAMIN B_{12} IN ACTIVATED SEWAGE SLUDGE. Science 114: 213.

——— Pepinsky, J. B., Jasewicz, L. and Porges, N.
AERATION AS A PARTIAL TREATMENT FOR DAIRY WASTES. Purdue Univ. Indus. Waste Conf. Proc. 6: 313–319.

Pepinsky, J. B., Porges, N., and Hoover, S. R.
APPLICATION OF RAPID CHEMICAL OXYGEN DEMAND TEST FOR DETERMINING ORGANIC POLLUTIONS. Purdue Univ. Indus. Waste Conf. Proc. 6: 367–374.

Porges, N., Pepinsky, J. B., and Jasewicz, L.
FEED YEASTS FROM DAIRY BY-PRODUCTS. Jour. Dairy Science 34: 615–621.

1952

Hoover, S. R., Jasewicz, L., Pepinsky, J. B., and Porges, N.
ACTIVATED SLUDGE AS A SOURCE OF VITAMIN B_{12} FOR ANIMAL FEEDS. Sewage and Indus. Wastes 24: 38–44.

——— Jasewicz, L., and Porges, N.
BIOCHEMICAL OXIDATION OF DAIRY WASTES. IV. ENDOGENOUS RESPIRATION AND STABILITY OF AERATED DAIRY WASTE SLUDGE. Sewage and Indus. Wastes 24: 1144–1149. Also Purdue Univ. Indus. Waste Conf. Proc. 7: 541–548.

——— and Porges, N.
ASSIMILATION OF DAIRY WASTES BY ACTIVATED SLUDGE. II. THE EQUATION OF SYNTHESIS AND RATE OF OXYGEN UTILIZATION. Sewage and Indus. Wastes 24: 306–312.

——— and Porges, N.
TREATMENT OF DAIRY WASTE BY AERATION. U.S. Bur. Agr. Indus. Chem. AIC 332, 7 pp.

Porges, N., Jasewicz, L., and Hoover, S. R.
MEASUREMENTS OF CARBON DIOXIDE EVOLUTION FROM AERATED SLUDGE. Sewage and Indus. Wastes 24: 1091–1097.

——— Pepinsky, J. B., Jasewicz, L., and Hoover, S. R.
BIOCHEMICAL OXIDATION OF DAIRY WASTES. III. FAILURE OF SODIUM NITRATE AS A SOURCE OF OXYGEN. Sewage and Indus. Wastes 24: 874–881. Also Purdue Univ. Indus. Waste Conf. Proc. 7: 33–43.

1953

Hoover, S. R.
BIOCHEMICAL OXIDATION OF DAIRY WASTES. Sewage and Indus. Wastes 25: 201–206, illus.

——— Jasewicz, L., and Porges, N.
AN INTERPRETATION OF THE B.O.D. TEST IN TERMS OF ENDOGENOUS RESPIRATION OF BACTERIA. Sewage and Indus. Wastes 25: 1163–1173.

Jasewicz, L., Porges, N., and Hoover, S. R.
BORAX AS A PRESERVATIVE OF DAIRY WAS E FOR THE B.O.D. TEST. Purdue Univ. Indus. Waste Conf. Proc. 8: 387–392.

Kountz, R. R.
DAIRY WASTE TREATMENT PILOT PLANT. Purdue Univ. Indus. Waste Conf. Proc. 8: 382–386.

Porges, N., Jasewicz, L., and Hoover, S. R.
A MICROBIOLOGICAL PROCESS REPORT. AEROBIC TREATMENT OF DAIRY WASTES. Appl. Microbiol. 1: 262–270.

1954

Hoover, S. R., Jasewicz, L., and Porges, N.
BIOCHEMICAL OXIDATION OF DAIRY WASTES. VI. RELATIONSHIP BETWEEN THE RATE OF PURIFICATION AND THE RATE OF OXIDATION AND GRAPHICAL ESTIMATION OF FIRST ORDER VELOCITY CONSTANTS. Purdue Univ. Indus. Waste Conf. Proc. 9: 71–79.

——— Jasewicz, L., and Porges, N.
THE MAGNETIC OXYGEN ANALYZER IN STUDIES OF OXYGEN UPTAKE. Water and Sewage Works 101: 81–83.

——— Jasewicz, L., and Porges, N.
MEASUREMENT OF OXYGEN TRANSFER. Instruments and Automation 27: 774–775.

Kountz, R. R.
BIG PROBLEM: DAIRY WASTES. STRIKING SOLUTION: BIO-OXIDATION. Food Engin. 26: 89–90.

——— and Villforth, J. C.
BIOLOGICAL OXIDATION AERATORS. Purdue Univ. Indus. Waste Conf. Proc. 9: 53–63.

Villforth, J. C.
THE VENTURI INJECTOR AS AN AIR DISPERSION DEVICE. M. S. Thesis, Pa. State University. Dept. Civil Engin., 46 pp., illus.

1955

Kountz, R. R.
DAIRY WASTE TREATMENT. Milk and Food Technol. Jour. 18: 243–245.

———
SIMPLIFIED DAIRY WASTE. Milk Prod. Jour. 46: 10–11, 54.

Porges, N.
RAPID BIO-OXIDATION METHOD OF WASTE DISPOSAL. Amer. Soc. Brewing Chemists Proc. 1955: 56–64, illus.

——— Jasewicz, L., and Hoover, S. R.
BIOCHEMICAL OXIDATION OF DAIRY WASTES. VII. PURIFICATION, OXIDATION, SYNTHESIS AND STORAGE. Purdue Univ. Indus. Waste Conf. Proc. 10: 135–146.

1956

Hoover, S. R.
TRANSFORMATIONS OF CARBON BY MICRO-ORGANISMS. Indus. and Engin. Chem. 48: 1419–1420.

——— Jasewicz, L., and Porges, N.
AEROBIC PROCESS FOR TREATMENT OF DAIRY WASTES. Internatl. Dairy Cong. Proc. 14 (v. 2, pt. 2): 238–242.

Jasewicz, L., and Porges, N.
BIOCHEMICAL OXIDATION OF DAIRY WASTES. VI. ISOLATION AND STUDY OF SLUDGE MICRO-ORGANISMS. Sewage and Indus. Wastes 28: 1130–1136.

Kountz, R. R.
DAIRY WASTE TREATMENT PLANT DESIGN. *In* Biological Treatment of Sewage and Industrial Wastes. Aerobic Oxidation (McCabe and Eckenfelder, eds.), v. 1, pp. 356–359.

———
EVALUATING PROPRIETARY AERATION DEVICES. *In* Biological Treatment of Sewage and Industrial Wastes. Aerobic Oxidation (McCabe and Eckenfelder, eds.), v. 1, pp. 212–214. Reinhold Publ. Corp., N.Y.

———
TOTAL OXIDATION TREATMENT. Purdue Univ. Indus. Waste Conf. Proc. 11: 157–159.

——— and Porges, N.
DAIRY WASTE TREATMENT BY AERATION. U.S. Dept. Agr. ARS (EURDD), Agr. Res. Serv. 73–16, 8 pp., illus.

Porges, N.
BIO-OXIDATIVE TREATMENT OF DAIRY WASTES. 3d Ontario Indus. Waste Conf., 55–61.

———
WASTE TREATMENT BY OPTIMAL AERATION—THEORY AND PRACTICE IN DAIRY WASTE DISPOSAL. Milk and Food Technol. Jour. 19: 34–38.

——— Jasewicz, L., and Hoover, S. R.
PRINCIPLES OF BIOLOGICAL OXIDATION. *In* Biological Treatment of Sewage and Industrial Wastes. Aerobic Oxidation (McCabe and Eckenfelder, eds.), v. 1, pp. 35–48. Reinhold Publ. Corp., N.Y.

——— Jasewicz, L., and Hoover, S. R.
SIMPLE METHOD FOR ESTIMATING OXYGEN VALUE OF WASTES. Indus. Wastes 1: 95–98, illus.

1957

Best, C. N.
AIR-DISPERSION SOLUTION IN A VENTURI INJECTOR. M. S. Thesis. Pa. State Univ. Dept. Civil Engin., 33 pp. illus.

Eckenfelder, W. W., Jr., and Porges, N.
MICROBIOLOGICAL PROCESS REPORT. ACTIVITY OF MICRO-ORGANISMS IN ORGANIC WASTE DISPOSAL. IV. BIO-CALCULATIONS. Appl. Microbiol. 5: 180–187, illus.

Porges, N.
CURRENT STUDIES ON DISPOSAL AND UTILIZATION OF WHEY. Wash. State Col. Ann. Pacific Northwest Indus. Waste Conf. Proc. 8: 153–156.

———
MICROBIOLOGICAL PROCESS REPORT. ACTIVITY OF MICRO-ORGANISMS IN ORGANIC WASTE DISPOSAL. I. INTRODUCTION. Appl. Microbiol. 5: 166.

——— and Jasewicz, L.
APPLICATION OF BIOCHEMICAL STUDIES TO DAIRY WASTE TREATMENT. Wash. State Col. Ann. Pacific Northwest Indus. Waste Conf. Proc. 8: 51–61, illus.

1958

Jasewicz, L., and Porges, N.
AERATION OF WHEY WASTES. I. NITROGEN SUPPLEMENTATION AND SLUDGE OXIDATION. Sewage and Indus. Wastes 30: 555–561, illus.

Porges, N.
DAIRY WASTES: DISPOSAL BY BALANCED BIOCHEMICAL BIO-OXIDATION. PART 1. Dairy Engineering (London) 75: 255–258, 294–297, illus.

———
DEVELOPMENTS IN DAIRY WASTE DISPOSAL. Mich. State Univ., Dairy Engin. Conf. Proc. 6: 92–99.

———
PRACTICAL APPLICATION OF LABORATORY DATA TO DAIRY WASTE TREATMENT. Food Technol. 12: 78–80.

——— Wasserman, A. E., Hopkins, W. J., and Jasewicz, L.
OXIDATION OF RADIOACTIVE GLUCOSE BY AERATED SLUDGE. Sewage and Indus. Wastes 30: 776–782, illus.

1959

Porges, N.
NEW ASPECTS OF WASTE TREATMENT. Appl. Microbiol. [In press.]

——— and Jasewicz, L.
AERATION OF WHEY WASTES. II. A C.O.D. AND SOLIDS BALANCE. [In press.]

——— and Jasewicz, L.
DAIRY WASTE CAN BE TREATED. [In press.]

APPENDIX

THE COD METHOD

The oxygen demand of a waste may be determined by a chemical procedure such as given in the "Standard Methods" (*2*) or by other methods. This chemical oxygen demand (COD) approximates the 20-day or ultimate biological oxygen demand (BOD) of dairy waste. By use of appropriate factors determined by experimentation, the 5-day BOD of the waste can be approximated. The method is not used to replace the standard 5-day BOD test, but it is of inestimable value in plant control of waste, as results are obtained in about 20 minutes. A rapid procedure was used in these studies made with dairy wastes. Details of the technique are given here.

Reagents used in the rapid chemical oxidation method are as follows:

1. Oxidizing agent prepared by adding 2.5 grams of $K_2Cr_2O_7$ to a mixture of 500 milliliters of concentrated H_2SO_4 and 500 milliliters 85 percent H_3PO_4. It is advisable to triturate the dichromate to a fine powder. Let stand a few days with occasional shaking until the dichromate is in solution. Filter through glass wool or decant with care, in order to obtain a clear oxidizing reagent free of particles.
2. Potassium iodide solution made by dissolving 55.3 grams KI in 200 milliliters water.
3. Standard 0.05 normal sodium thiosulfate titrating solution prepared by dissolving exactly 12.41 grams $Na_2S_2O_5.5H_2O$ and making up to 1 liter, or by diluting a more concentrated solution to the desired strength.
4. Starch indicator solution made by dispersing 1 gram of starch in about 25 milliliters water and adding 75 milliliters boiling water.

The procedure follows:

1. Place exactly 50 milliliters of the dichromate oxidizing solution in a 500-milliliter Phillips beaker or Erlenmeyer flask. Twenty-five-milliliter solution has been used also, with proportional reduction of other reagents and at reduced costs.
2. Add exactly 5 milliliters of the waste sample to the oxidizing solution. The strength of the waste should be between 50 and 1,500 p.p.m. If of more than 1,500 p.p.m., dilute the sample, or add less and make up with water to give 5 milliliters.
3. Place on hot plate and heat uniformly so that oxidizing solution reaches a temperature of 165° to 170° C. in 6 minutes.
4. Remove immediately from heat, place in water bath, and cool to room temperature.
5. Add 200 milliliters of distilled water and cool again in water bath.
6. Add 10 milliliters of the potassium iodide solution and titrate immediately with the standard 0.05 normal thiosulfate solution, adding starch near the end point. The color change is from dark blue to pale blue green. Ferroin may also serve as an indicator (*18*).
7. Make a blank determination, using 5 milliliters water.
8. The total oxygen demand in parts per million or milligrams per liter is equal to 80 times the difference in titration in milliliters between the water blank and the sample. If the original waste was diluted for testing, this must also be taken into consideration. The calculation follows:

$$\frac{D\times 0.05\times 8}{5}\times 1{,}000=D\times 80 \qquad (4)$$

D=difference in titration between the blank and sample;
0.05=normality of the thiosulfate;
8=milligram-oxygen equivalent to 1 milliliter normal thiosulfate;
5=volume taken for oxidation;
1,000=conversion value to obtain milligrams per liter or parts per million.

The result approximates the total or ultimate amount of oxygen required for the oxidation of the waste or sample. The proportion of the oxygen requirement due to sugar or casein can be ascertained by determining the amount of sugar or protein and converting to oxygen demand. Thus, 1 gram of lactose anhydride requires 1.123 grams of oxygen, while a gram of protein requires about 1.44 grams of oxygen for total oxidation. Likewise, an estimate of the total sludge weight may be obtained by multiplying the COD of the sludge by 0.8, as 1 gram of sludge has a COD of about 1.25.

WHEY WASTES

Dairies that produce large quantities of cheese will find that excess whey in the dairy waste can cause trouble in the treatment unit. The whey, which may contain 5 percent solids, can be treated by biochemical oxidation if a nutrient balance and aerobic conditions are maintained, but the enormous oxygen demand makes the process costly. The possibility of returning whey to the farm for livestock feeding or of converting whey to useful products should be investigated.

Infrequent inclusion of whey will not harm the normal dairy waste process, especially when the quantity of whey solids is small compared to milk solids. If the rate of whey discharge is not rapid, here will be enough nitrogen in the whole milk waste and in the seed sludge for bacteria to dispose of the whey.

Although ejector aeration units recover rapidly, shock loading by dumping large quantities of whey is not a recommended practice. In one case, the weekly discharge of the equivalent of 700 pounds of whey solids to a treatment plant designed for 300 pounds of milk solids per day did not appear to interfere with the aeration process. The most noticeable effect was an accumulation of sludge. During the pilot plant study, a large quantity of whey was accidentally discharged into the treatment unit designed for 10,000 gallons of dairy waste per day. This caused excessive foaming and incomplete purification. Chemical analysis revealed a nitrogen deficiency caused by the high lactose content of the whey. The condition was corrected by adding 100 pounds of ammonium sulfate to balance approximately 5,000 gallons of whey.

Nitrogen is essential for the proper growth of micro-organisms. Ordinary dairy waste is an ideal food for bacteria because it has much the same composition as milk. Its COD to nitrogen ratio is approximately 25 to 1. The ratio for whey is much higher, 50 to 1, because the cheese process removes the principle nitrogen-containing compound, casein. This leaves a material of high sugar and low nitrogen content. If whey or similar materials are to be consumed by bacterial oxidation, nitrogen must be added to maintain a level suitable for the bacteria.

Each 1,000 pounds of liquid whey contains about 50 pounds of solids, which is about equal to 50 pounds COD. To maintain a 25 to 1 COD to nitrogen ratio requires 2 pounds of nitrogen. Adding this amount would never be necessary, because the analysis of whey shows 2 percent soluble nitrogen. The maximum nitrogen addition to whey would be 1 pound, which can be supplied by 5 pounds ammonium sulfate.

Part of the nitrogen content of the seed sludge may also be utilized to reduce the cost of nitrogen supplementation. A well-aerated stabilized sludge contains 11.25 percent nitrogen and has a COD to nitrogen ratio of 12 to 1 on a dry-weight basis (*10*). Sludge-waste mixtures need at least 7 percent nitrogen to effect adequate treatment. The difference is available for bacteria during whey consumption. Each pound of sludge solids in the unit can give up enough nitrogen for the bacteria to utilize 1 pound of whey solids. If the proportion of whey to sludge exceeds this, nitrogen in a readily soluble form must be furnished.

EJECTORS AS AERATION DEVICES

Of the many devices available, the ejector was originally selected for studying large-scale aeration of dairy wastes because it had separate pipe connections for air and liquid inlets as well as a discharge outlet. It was known as an effective mixer of two inlet streams. As designed, the two streams, air and water, were to be controlled by separate pumps. Tests soon showed that an air pressure pump was unnecessary, because the ejector could readily dissolve oxygen at the high rates required. The ejector is simple to operate, contains no moving parts, and is low in initial cost and upkeep. The use of ejectors or mixing jets for waste treatment has been reviewed (*22*). They were suggested for this purpose as early as 1905. Their use at a commercial installation for treating chemical wastes was later patented (*20*). Some installations that use small-size ejectors in treating dairy waste were reported and discussed (*22*).

Ejectors operate on the principle of creating a high velocity stream that is directed into the throat of a venturi tube. Figure 8 shows a cross-section through the type recommended. The waste is pumped through the device and enters at the left, where the reduced size of the tip of the jet increases the stream velocity. This fast-moving liquid enters the venturi tube mixing with the air that is drawn in through the air intake. The velocity and turbulence of the mixture gives the device its tremendous oxygen-dissolving ability.

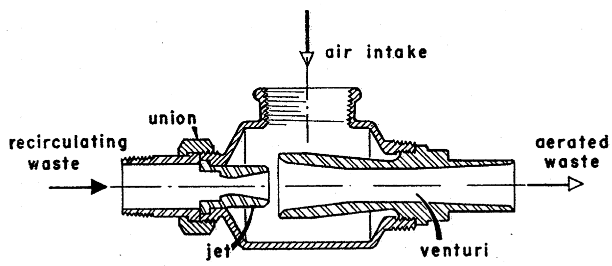

FIGURE 8.—Cross section through model XL–96 ejector.

The ejector used in the investigations reported in this Handbook was selected after three sizes and two styles were studied. Comparison of the efficiency of the three sizes is illustrated in figure 9. The largest of the three, model XL–96, size 7A (steam type), is recommended for dairy waste aeration. It will do the work of two units of the next smaller size (5A) and six units of the smallest size studied (3A). Its large physical dimensions almost completely prevent clogging by debris normally found in the wastes. Clogging has caused serious maintenance problems at treatment plants where small ejectors have been installed. Closer mesh screens at the pump suction for small ejectors have only partially alleviated the problem, because the screens must be cleaned more frequently.

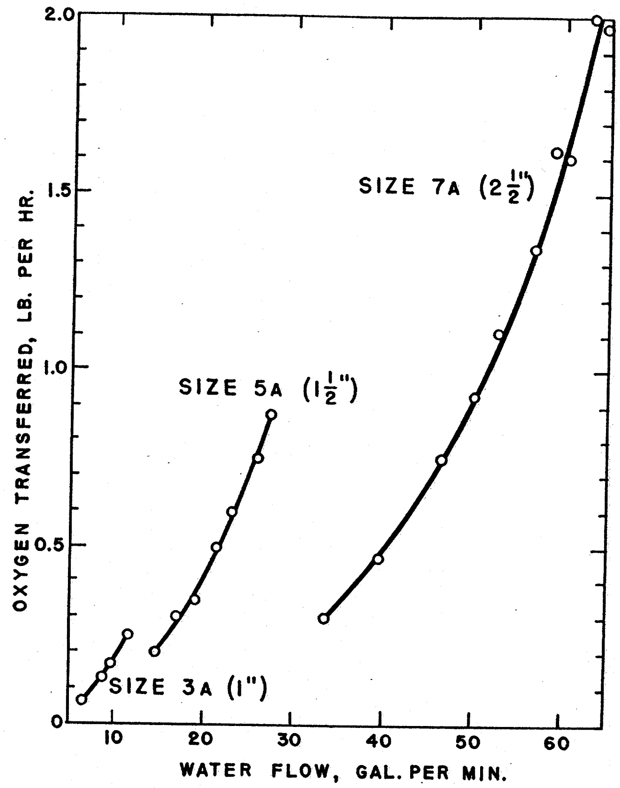

FIGURE 9.—Oxygen transfer to a sulfite solution through three sizes of ejectors at varying rates of water flow.

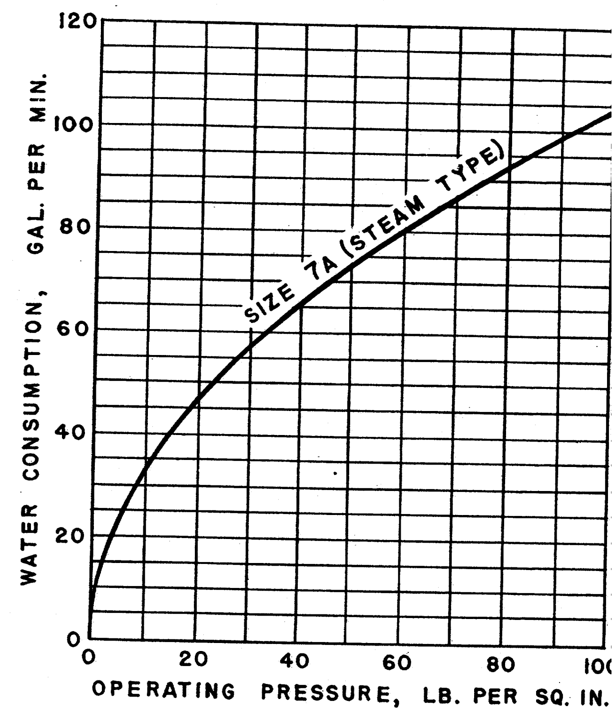

FIGURE 11.—Flow versus pressure for one ejector.

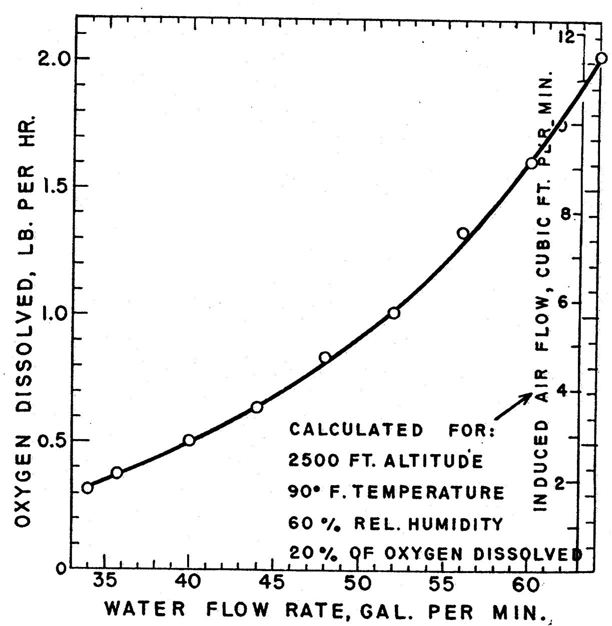

FIGURE 10.—Relation of oxygen dissolved and calculated aspirated-air volume to water flow for one ejector, size 7A, steam type, immersed 4 feet.

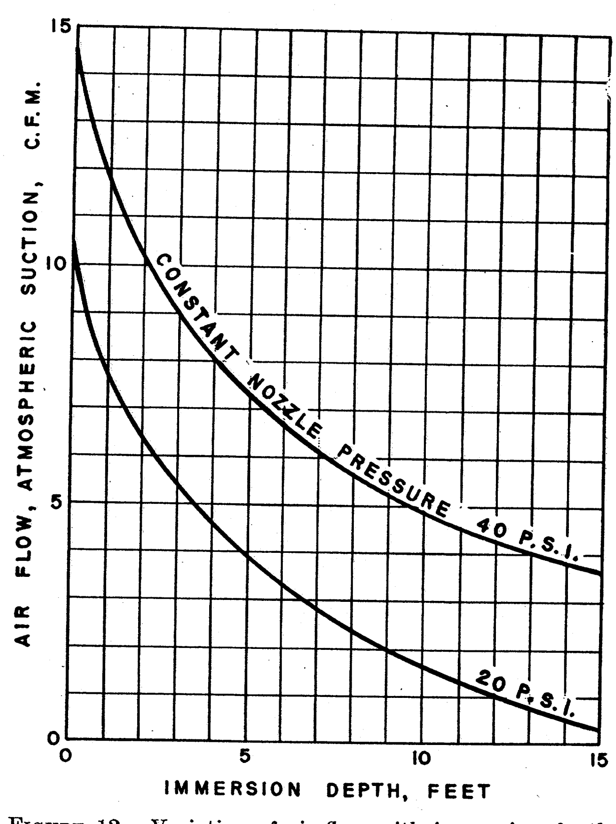

FIGURE 12.—Variation of air flow with immersion depth for one type ejector under constant nozzle pressure.

A formula was developed relating the oxygen dissolving ability of this specific ejector to the flow of liquid through its nozzle.

$$\text{Oxygen dissolved (lb./hr.)}=0.165\ V^{2.35} \qquad (5)$$

$$\text{where } V=\frac{\text{nozzle flow (c.f.s.)}}{\text{nozzle diameter (ft.)}}$$

The performance of the recommended ejector is summarized in figure 10 for water rates ranging from 34 to 64 gallons per minute. These rates were determined from the oxidation of a solution of sodium sulfite (*3*). The curve may be used to determine if sufficient oxygen is being supplied at reduced pressures.

Figure 11 is introduced to show the approximate water pressure needed to force varying amounts of liquid through the same ejector. The chart has been prepared from the manufacturer's published data.

The depth of immersion of the ejector influences the amount of oxygen that can be dissolved at a given nozzle pressure. In figure 12, data for a similar ejector (same size, different style) have been plotted to show how the amount of air aspirated will vary with the depth of immersion of the device. No data are presently available on this aspect of the performance of steam-type ejectors. Furthermore, the data presented should not be confused with figures given elsewhere for dissolved oxygen. However, the conclusion that the performance of these ejectors is improved when operating at shallow depths appears inescapable. This is in addition to evidence assembled during the study that the overall efficiency of a pump and ejector system is greatest at the lowest rate of water flow consistent with proper functioning of the ejector.

The manufacturer states that air will be aspirated and the device work efficiently at a minimum of 20 p.s.i. nozzle pressure. This must be at least four times the pressure against which the device is aimed. Careful testing of all systems is recommended, particularly those designed with low nozzle pressures, to insure some allowance for wear on pump impellers and enlargement of ejector nozzles.

To make the data available from the study complete, the following formula is presented. The volume of air aspirated during the test with sulfite solution was also related to the nozzle stream-surface velocity.

$$\text{Volume of air aspirated (c.f.m.)}=2.30\times V^{3.52} \qquad (6)$$

$$\text{where } V=\frac{\text{volume of stream (c.f.s.)}}{\text{nozzle diameter (ft.)}}$$

OXYGEN CONTENT OF THE ATMOSPHERE

In applying aeration devices to dairy waste treatment, some difficulty may be encountered in hot, humid regions. Most air equipment is rated for the standard conditions of 70° F., 50 percent relative humidity, and a barometric pressure of 29.92 inches of mercury. Figure 13 has been included to demonstrate the increased air

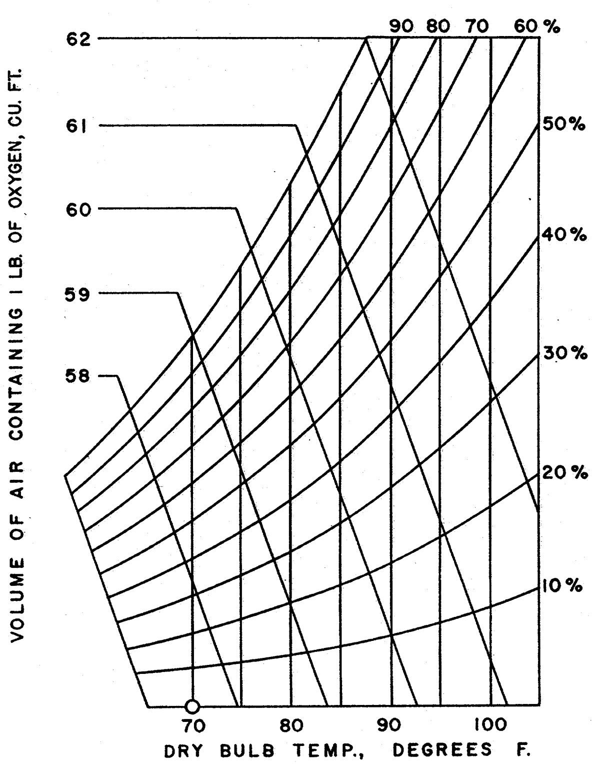

FIGURE 13.—Chart for relating volume of air containing one pound of oxygen to temperature and relative humidity.

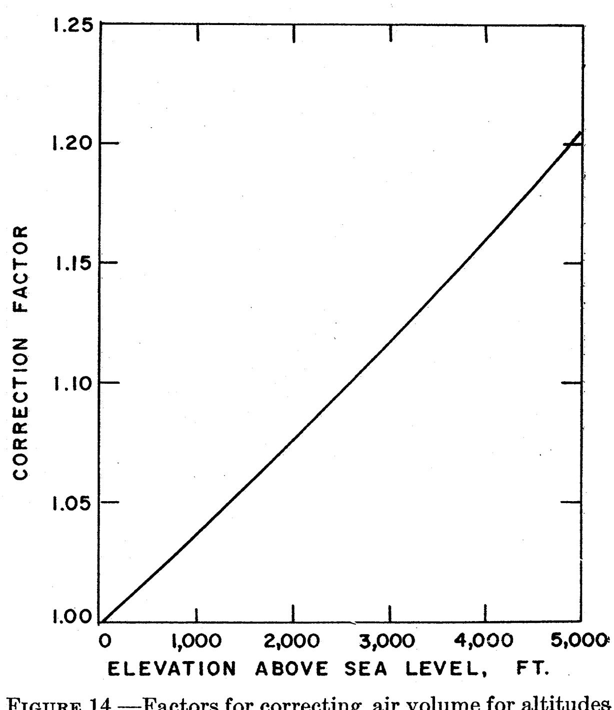

FIGURE 14.—Factors for correcting air volume for altitudes above sea level.

volume required to contain a pound of oxygen at nonstandard conditions. Values to be obtained from this chart will apply only at a constant barometric pressure equivalent to sea level. A separate chart (fig. 14) is used to correct for higher elevations. By multiplying the factor taken from figure 14 with the value for temperature and relative humidity from figure 13, the correct quantity of air to contain 1 pound of oxygen can be closely estimated. In the worst cases, the correction may amount to as much as 25 percent.

The information noted in this section makes no reference to the efficiency of the apparatus introducing the oxygen into solution. Calculations to determine volumes of supply air for all devices must include a factor for the percentage of oxygen dissolved by the device subject to the corrections described above.

EXCESSIVE FOAMING

Excessive foaming has been troublesome at times. In this type of treatment system foaming does not usually occur while the waste is being added and assimilated by the sludge. It tends to occur toward the end of the assimilation period and at the start of the endogenous phase. Overflow of the foam may be avoided at any time by interrupting the air supply. This may safely be done only if the aeration system has the ability to quickly replenish dissolved oxygen. If necessary, assimilation may also be interrupted by a period of settlement and draining to lower the water level when foaming occurs.

Foaming may also be caused by overaeration. As the plant must be designed to care for the waste produced during the highest seasonal flow of milk, it may prove to have too large a capacity at other times. This happens more frequently when equipment of low oxygen transfer efficiency has been used. In such cases a large quantity of air must flow through the liquid to provide the required oxygen. Barring conditions caused by the presence of unnatural materials in the waste, foaming will usually subside when aeration is stopped or substantially reduced.

HEATING THE DAIRY WASTE

As with other biological processes, the rates of assimilation of the waste and respiration of the sludge vary with the temperature of the solution. Fortunately, many dairies discharge wastes at a temperature favorable for biological treatment. Although the process is fairly hardy, some retardation may be expected if the temperature in the tank falls much below 70° F.

The use of hot water and steam in the dairy produces a waste with an average temperature of 85° to 90° F. This is ideal for the bacteria that purify dairy waste. If the temperature in the aeration tank were to drop to 55° or 60°, many forms of bacteria could not survive or reproduce and treatment would be retarded or incomplete. Some dairies may find it advisable to heat the waste.

Heating the dairy waste by means of steam coils is unsatisfactory, because the waste cooks onto the pipes and seriously impairs heat transfer. Waste hot water or steam that is allowed to discharge elsewhere can be repiped to be included with the waste to be treated. A simple solution is the use of hotter water in dairy plant cleaning operations, but this may be too costly. Other piping changes may be possible that will prevent large flows of cold water from diluting and cooling the warm waste. Direct addition of waste steam to the tank is probably the most practical method of heating dairy waste.

If piping modifications do not bring the waste to a desirable temperature for satisfactory operation of the waste plant, then steam heating may have to be applied. The dairy plant operator would then need to know the size of pipe and the amount of steam required. The chances are excellent that only a small pipe would be actually needed, but the factors in determining the size of the pipe are explained.

The first step is to find the quantity of heat necessary to correct the temperature of the waste. The general formula for this for unit time would be:

$$Q = Wc\ (t_2 - t_1) \tag{7}$$

where

Q = quantity of heat (B.t.u. (British thermal units)/hr.)
W = total weight of material (lb.)
c = specific heat of the substance, which in this case will be 1, the same as water
$t_2 - t_1$ = initial temperature subtracted from the final temperature (° F.)

If it is assumed that the average waste temperature, 65° F., should be 85° and 1,200 gallons per hour are to be treated, the following would be the calculation:

(*a*) Quantity of heat (by formula 7):

$$\text{Heat (B.t.u./hr.)} = 1{,}200 \times 8.34 \times 1 \times (85° - 65°) = 200{,}160 \text{ B.t.u. per hour}$$

The number of pounds of steam required to supply this much heat depends on the steam pressure available. For a low pressure source, the following calculations can be made to determine the size of pipe and quantity of steam to be used.

The amount of heat given up by each pound of steam is first determined. This is the difference between the total heat in the steam as it enters the tank and its final condition after reaching the temperature of the surrounding mass of liquid. The example below is for steam at 1.3 pounds per square inch, gage:

(*b*) Heat per pound of steam:

	Heat of liquid	Latent heat of evaporation	Total heat
	B.t.u.	*B.t.u.*	*B.t.u.*
Entering steam	184.4	967.6	1,152.0
Final (at 85° F.)	53.0	0	53.0
Heat available per pound			1,099.0

(*c*) Steam needed each hour:

$$\frac{200{,}160 \text{ B.t.u.}}{1{,}099}=182 \text{ pounds}$$

In order to determine the size of pipe necessary to supply this amount of steam, its density must be known in cubic feet per pound. The constants of steam are available in any standard table of properties of saturated steam. A reasonable velocity for low-pressure steam of 6,000 feet per minute would be used in the standard velocity formula for determining the size of pipe needed:

$$V=\frac{A\times B\times 1{,}728}{C\times 60\times 12} \qquad (8)$$

Where V=velocity in feet per minute;
A=pounds of steam per hour;
B=volume of steam in cubic feet per pound at the stated pressure (24.75 cubic feet at 1.3 pounds pressure);
C=area of pipe in square inches;
1,728=cubic inches per cubic foot;
12=inches per linear foot;
60=minutes per hour.

Transposing and simplifying, formula (8) becomes

$$C=\frac{A\times B\times 2.4}{V} \qquad (9)$$

(*d*) Area of pipe (by formula 9):

$$C=\frac{182\times 24.75\times 2.4}{6{,}000}$$

$$=1.8 \text{ square inches}$$

Next, convert this cross section area to internal diameter of pipe. A standard table shows that a pipe 2 inches in diameter has ample cross-section area to deliver the desired amount of steam. However, if the length of the run from the steam source to the assimilation tank were very long, the recommended steam line should be increased one size to 2½-inch pipe.

WASTE TREATMENT SYSTEMS USING EJECTOR AERATION

A number of dairy plants now treat waste successfully by using ejectors for rapid aeration. Some treatment units use as few as 4 ejectors, whereas others use as many as 26.

This Handbook recommends that operating installations should be inspected prior to the design and construction of a new waste disposal system. More than 125 successful plants were in operation in 1958. A partial list of these plants may be obtained from the Eastern Utilization Research and Development Division, 600 East Mermaid Lane, Wyndmoor, Pa.

INDEX