

WATER SUPPLY AND WASTE DISPOSAL FOR MILK PROCESSING PLANTS

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The procurement of water, its use in a milk plant and its disposal can be considered as a continuous process. It enters the plant in a natural state, is purified or treated as necessary for use, picks up liquid or solid wastes, is treated to remove all or part of these wastes, and is again discharged into a natural body of water. Some of these steps may take place outside the milk plant. Water may, for example, be obtained from a municipal or other public water supply system in a condition ready for use, or on the other hand the wastes from a milk plant may be discharged into a public sewer system for treatment in a sewage disposal plant and ultimate discharge with other liquid wastes from an entire city. There are, however, many milk processing plants so located that the entire operation must be carried out by the plant itself. In this discussion, the water cycle is broken down into three parts: water supply, water treatment, and waste treatment. These three aspects are closely connected and interdependent.

WATER SUPPLY

The selection of a source of water is dependent first of all upon its quality. The source must be either of a quality suitable for use without treatment, or of such quality that it can be treated successfully at a reasonable cost. A hard water—that is, one containing mineral compounds of calcium and magnesium—can usually be softened by any of several methods at a relatively low cost. On the other hand, a salty water, containing salts of potassium and sodium, may require distillation, double ionic exchange or other comparable treatment, which is relatively expensive. A surface water containing such natural pollutants as mud or organic matter can usually be treated at a reasonable cost, but a surface water containing such industrial wastes as chromium or phenolic compounds may be very expensive to treat.

If a water source is of a suitable quality, the next and only remaining consideration is that the quantity available must be sufficient, and this

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amount must be dependable continuously at all times and seasons. The yield of a stream or a well may, for example, diminish during certain periods of the year, or at times of prolonged drought, to the point that plant operations must be reduced or stopped. Studies of water yield should therefore take into account yields over a full year, and the effect of an abnormally dry year.

Raw Water Quality

The International Standards for Drinking-Water (World Health Organization, 1958) specify that the following toxic substances should not be present in communal water supplies in amounts greater than indicated:

Lead (as Pb)	0.1 mg/l *
Selenium (as Se)	0.05 mg/l
Arsenic (as As)	0.2 mg/l
Chromium (as Cr hexavalent)	0.05 mg/l
Cyanide (as CN)	0.01 mg/l

* mg/l = milligrams per litre.

The water supply for a milk processing plant should be of drinking-water quality, and these substances consequently should not be present in the water as used in the plant in greater concentrations than indicated. Normal water treatment processes may not materially reduce these constituents; hence, if any of these toxic substances are present at any time in the raw water in excessive concentrations, the source in question should be rejected. If there is no alternative source, competent technical advice should be sought on effective methods for their removal.

Chlorides and sulfates are not easily removed by treatment, and their concentrations in the water source should be examined. If possible, a source should be selected that contains no more than 200 mg/l of either. In situations where all the available sources are highly mineralized, the allowable concentrations can be increased to 400 mg/l for sulfates and 600 mg/l for chlorides, but expensive trouble can be expected from the continued use of such water.

Phenolic substances are highly objectionable in the water supply of a milk processing plant because they impart a damaging taste and odour to any dairy product with which they come in contact. Phenols are not readily removed by ordinary water treatment processes, and should not be present in the raw water in concentrations greater than 0.001 mg/l expressed as phenol.

There are other considerations to be taken into account before a source is accepted for a milk plant supply. Water which is contaminated with sewage or sewage effluents should be viewed with great suspicion even though the water is subsequently purified. In any process of water treatment, human or mechanical failure is to be expected at some time. Sole

reliance must not be placed on treatment processes alone; other concurrent safeguards to water quality must be established. An epidemic of disease in a community, traced to the contamination of a milk supply, can put a dealer out of business overnight, and if negligence can be proved, an epidemic can lead to ruinous claims for damages. It is not only a social responsibility, but good business judgement to safeguard the product against harmful contamination. One safeguard is to make sure that the water source is as pure as possible before treatment. There are two measures to be taken: a sanitary survey of the proposed source, and bacteriological study of samples from the source.

A sanitary survey should, if possible, be made by an experienced public health expert, preferably a sanitary engineer. It should cover not only conditions existing during the period of the survey, but also potential sources of pollution. A stream may, for example, be relatively free from harmful bacteria during dry periods, but badly contaminated after rainstorms. A well may ordinarily produce pure water, but may become contaminated if the well-top is flooded. Chance or accidental episodes are doubly dangerous if they are unexpected. Great reliance must be placed on the skill and experience of the person making a sanitary survey of a water source.

Bacteriological studies should not be confined to the examination of a single sample of water, no matter how complete the examination may be. Much more can be gained from even simple examinations of a series of samples, taken at different times and under different conditions, than from an elaborate and exhaustive examination of a single sample. No one sample is fully representative of the supply. This is particularly true of surface water, which may change greatly in quality within a period of a few hours. It is less important to take frequent samples from a deep well which has been in use for some time, and where the quality does not change greatly or often. Absolute limits for the bacteriological quality of raw water are difficult to set, since the efficiency of bacterial removal by any treatment process depends so much on the design of the process and the calibre of operation. Fair & Geyer (1954) (p. 701), basing their conclusions on results from large municipal filtration plants and on the US Public Health Service standards for drinking-water, indicate the following as the maximum permissible concentrations of coliform organisms in raw water which will result in a suitable quality of treated water:

<i>Treatment process</i>	<i>Turbid river water (MPN* coliforms)</i>	<i>Clear lake water (MPN* coliforms)</i>
1. Chlorination	80	50
2. Flocculation, settling and rapid sand filtration	80	60
3. (2) and pre-chlorination	3500	
4. (2) and post-chlorination	6000	4500

* MPN = most probable number of organisms per 100 ml of water.

For small plant operation, and particularly where pressure sand filters are used, these values would be considerably lower.

In summary, before a source of water can be considered suitable for a milk processing plant the following investigations should be undertaken: a limited chemical examination of the water, including an estimation of the substances mentioned on page 500; a sanitary survey, to disclose existing and potential sources of pollution; and a series of bacteriological examinations, to provide an index of harmful pollution. If these three steps, taken together, indicate that the raw water quality is suitable, the source can be considered further.

Quantities Required

The quantity of water required in a milk processing plant depends upon the size of the plant, generally expressed in terms of the maximum weight of milk handled during any one day, and the processes involved. The daily volume of water required may vary widely, depending mainly on the availability of water and the control of all water-using operations in the plant. In operations where the process is one of continuous flow, the amount of water needed for rinsing and washing is not necessarily proportional to the amount of product processed. Less water is needed for cooling equipment where the cooling water is recirculated. A tabulation should be made of each process, and an estimate of water requirements prepared in detail. The processes to be considered would include the following:

Human use:

- Water closets
- Bathing and hand-washing facilities
- Drinking-water and catering

General plant use:

- Washing of premises
- Washing of vehicles
- Plant laboratory
- Maintenance of grounds

Cooling:

- Cooling of product
- Condensers
- Refrigeration machines

Processing of product:

- Washing of e.g., butter, curd
- Use in product

Cleansing of equipment, cans, bottles.

Power production:

Boiler feed

Steam production

Power-plant cooling water

As a general value, the amount of water required ranges from about one half to double the amount of milk handled, although the figure may be as high as nine times the milk volume. An approximation commonly used is that the amount of water required equals the amount of milk received. It is dangerous, however, to accept these approximations without making a detailed water-use analysis.

Information on the techniques of estimating water yields from different sources, including both surface water and ground water sources, can be obtained from any reliable textbook on water supply engineering. Wagner & Lanoix's (1959) treatment of the subject is particularly valuable since it deals with small supplies of a nature likely to be used by milk plants. Other sources of information would include the Institution of Water Engineers (1961), Fair & Geyer (1954), and Babbitt & Doland (1949).

Collection of Water

The methods of collecting water and bringing it to the point of use are so numerous and varied that they cannot be described in detail in this chapter. If the scale of the water supply permits, advice should be sought from a competent engineer. This is particularly the case if surface water is to be impounded, for failure of a dam, dyke or retaining structure can lead to serious damage to property and possible loss of life. Reference to the literature listed in the accompanying bibliography will provide useful suggestions and alternatives that might be considered for water collection structures. Particular emphasis is given to the book by Wagner & Lanoix, since it embraces experience in many different parts of the world. Reference is also made to the chapter by Clark in the present volume entitled "Water Supply on the Dairy Farm" and to its bibliography (see page 143).

WATER TREATMENT

Water treatment may be necessary to make the water safe, palatable and neutral, that is, neither scale-forming nor corrosive. Safety relates to the destruction or removal of pathogenic organisms which may infect plant personnel or the product. Palatability relates to such physical and chemical characteristics as tastes, odours, turbidity and presence of iron or manganese. The neutrality of water relates to acidity, alkalinity, hydrogen-ion concentration (pH), and hardness.

Chlorination

Chlorination, or an equivalent process, is a necessary step in the treatment of any surface water, and for any other water which on any occasion contains coliform bacteria. Active chlorine can be applied to water in the form of gaseous chlorine, calcium hypochlorite and sodium hypochlorite. Calcium hypochlorite is available either as chlorinated lime (25%-30% available chlorine) or as a high-test hypochlorite (about 70% available chlorine). The object of chlorination is to bring active chlorine into contact with all portions of the water being treated without interruption, in such concentrations, for such periods of time and under such conditions that all pathogenic bacteria are destroyed, and to do so without producing deleterious chlorinous tastes and odours. To be treated successfully, the water should be free from turbidity and from constituents that influence the effectiveness of the process. Suspended solids (turbidity) may shield embedded bacteria from the action of the chlorine. Organic matter in solution reacts with chlorine chemically and destroys its disinfecting properties. Ammonia reacts with chlorine to form chloramines, which have a lesser disinfecting property than free-residual chlorine. Alkalinity and a high pH value (above about pH 7.6) reduce the disinfecting capacity of chlorine. Nitrites combine with chlorine and destroy its disinfecting capacity, and at the same time interfere with the orthotolidine test, commonly used to determine the amount of available chlorine present in the water. Iron and manganese in the reduced state react with chlorine and destroy its disinfecting capacity, and when these metals are present in concentrations greater than about 1 mg/l, they interfere with the orthotolidine test. The temperature of water influences chlorination; at higher temperatures the bactericidal rate is higher, but chlorine tends to disappear from the water faster.

The minimum period of contact after admixture of chlorine should be about 10-15 minutes, depending on such conditions as temperature, alkalinity, pH and the presence of ammonia. Where treated water is held in a storage tank, it is desirable to apply the chlorine in advance of this tank to permit several hours of contact with the chlorine before the water is used.

The amount of chlorine applied to water should be based on tests made at the point of use. Tests should be made by the sodium-arsenite orthotolidine test to eliminate the effect of interfering substances. Better results can almost always be obtained, from the standpoint of effective disinfection and also reduction in chlorinous tastes and odours, by maintaining a free-chlorine residual, commonly known as break-point chlorination. Details of the laboratory techniques are given in the International Standards for Drinking-Water, Annex 4, p. 69 (World Health Organization, 1958).

Cox¹ has worked out a comparison of the effects of free-residual and combined-residual chlorine, which shows the benefits of maintaining break-point chlorination:

Recommended minimum concentrations of free-residual chlorine versus combined-residual chlorine to ensure effective disinfection

<i>pH value</i>	<i>Minimum concentration of free-residual chlorine; disinfecting period at least 10 min. (p.p.m.)</i>	<i>Minimum concentration of combined-residual chlorine; disinfecting period at least 60 min. (p.p.m.)</i>
6.0- 7.0	0.2	1.0
7.0- 8.0	0.2	1.5
8.0- 9.0	0.4	1.8
9.0-10.0	0.8	Not recommended
10.0 +	0.8 + (with longer contact)	

Coagulation

A study of a water source—for example, a lake which is relatively clear but which contains objectionable algae—may indicate that it is suitable for filtration without the use of chemical coagulants ahead of the filters, but most surface waters contain, at times or continuously, such high turbidity that the preliminary step of coagulation is necessary. Filtration for iron and manganese removal do not require chemical coagulation, but may require aeration and pre-sedimentation. The design and construction of water filtration plants is a specialized undertaking, and warrants the employment of a qualified engineer.

Water containing more than 5-10 units of turbidity, or water which is actually or potentially contaminated with cysts of enteric disease organisms such as *Endamoeba histolytica*, or eggs of intestinal worms, requires filtration. Cysts and ova are not completely destroyed by chlorination alone, but are effectively removed by careful and suitable filtration.

Coagulation consists of adding a chemical coagulant to the water, which reacts with compounds in the water to form a gelatinous floc, to which are drawn minute particles of clay or other solids which are too small to settle by themselves. If, after the addition and mixing of the coagulant and the formation of the initial floc, by slow and gentle movement the small particles are brought into contact with each other, they adhere together and build up into masses large enough to be visible and settle rapidly through the water. This process is called flocculation. If, after a floc with good settling properties is formed, the water is conducted gently into a quiescent tank, the flocculent matter will nearly all settle to the bottom within a period of an hour or two, and the clarified water can be withdrawn from the top, ready for filtration. Filtration consists in straining out any material which has

¹ Cox, C. R. *Operation and control of water treatment processes*, Geneva (World Health Organization: Monograph Series, in preparation).

not already settled, including floc, cysts and ova, having a size greater than the effective pore size of the filter. Coagulation of turbid water is usually necessary because clay particles are generally smaller than the filter's effective pore size, and in their natural state simply pass through the sand.

The chemicals commonly used for coagulation are alum (aluminium sulfate), copperas (ferrous sulfate), chlorinated copperas, ferric sulfate and ferric chloride. By far the most common is alum.

When alum is added to water containing natural alkalinity, it reacts with the dissociated hydroxyl ions to form aluminium hydroxide. This has the effect of reducing the alkalinity of the water and also of reducing the pH. Both of these effects are of importance. There must be sufficient alkalinity in the water to react with all the alum present, otherwise dissolved alum is carried forward through the filters and causes trouble when the water is subsequently used. Furthermore, the nature of the floc formed is strongly dependent upon the pH, but in a very complex way. If there is insufficient alkalinity to react with the alum, or if the pH is depressed below about 5.5, it is necessary to add alkalinity to the water, usually in the form of lime or sodium carbonate.

Reactions between alum and natural alkalinity in various waters are influenced by so many factors that it is virtually impossible to arrive at a theoretical determination. As a general guide, one p.p.m. of alum reacts with:

0.45 p.p.m. natural alkalinity, expressed as CaCO_3

0.30 p.p.m. of 85 % quick lime as CaO

0.35 p.p.m. of 95 % hydrated lime as $\text{Ca}(\text{OH})_2$

0.48 p.p.m. of soda ash as Na_2CO_3

The above approximate amounts of added alkali are those required with alum for the formation of an aluminium hydroxide floc without causing a change in the alkalinity of the treated water.

The effect of alum on the pH of natural waters is also of importance. The pH range for coagulating turbid waters is from about 5.7 to 8.0. Highly coloured waters may coagulate best at pH 4.4-6.0. Consequently, the addition of lime or soda ash should be governed to a large extent by the effect on the pH, and in some cases other coagulant aids such as sodium aluminate or activated silica might be useful.

Because of the difficulty in arriving at a theoretical determination of the optimum dosages of alum and added alkalinity, if it is needed, the best course usually is to make a series of jar tests, in which serial doses of the chemicals are added to a number of jars and stirred in the laboratory under standard conditions of speed, time and temperature. Jar tests are not exactly comparable to plant conditions, but with experience they give an excellent guide.

The addition of coagulants and coagulant aids should be at a point of great turbulence, to ensure very rapid or "flash" mixing into the entire volume of water being treated. Turbulence may be secured by mechanical means, or by hydraulic means, for example at a pipe outlet or weir. Following the initial quick mix, the design of a plant should provide for about 15-30 minutes of gentle agitation to give an opportunity for the floc particles to build up to their optimum size. Agitation should not produce too much shear, which would break up particles as they form, but should be great enough to prevent the floc from settling. If paddles are used, the peripheral speed should not exceed about 2 ft (0.6 m) per second. If hydraulic currents or jets are used to produce turbulence, their maximum velocities should be about 60 % of the above figure. Compressed air diffusers are also effective in flocculation tanks. Although these figures represent maximum velocities, it is often necessary to use lower velocities to preserve fragile floc. The lower limit of flocculating velocities is about 0.3 ft (0.09 m) per second, or just sufficient to prevent settling. It is desirable to provide a variable speed of agitation within these limits. Best results are obtained with velocities of about 1.0-1.4 ft (0.3-0.42 m) per second. Higher velocities are favoured for turbid waters and lower velocities for highly coloured waters. Flocculation should extend over a period of 10-30 minutes. In general, a longer period permits a lower coagulant dose and gentler agitation.

Sedimentation

There are six factors that influence sedimentation:

- (a) characteristics of the floc
- (b) temperature of the water
- (c) the period of time of sedimentation
- (d) the depth of the sedimentation basin
- (e) the horizontal area of the sedimentation basin
- (f) the " surface overflow rate "

Floc is characterized by its large bulk in relation to its weight. Flocculation should be directed to the formation of a dense, firm floc, and to the avoidance of a light, feathery floc. A conservative figure, frequently used in design, is that floc will settle at a rate of 2.5 ft (0.75 m) per hour. A good floc will settle much more rapidly than this, and a settling velocity of 10 ft (3 m) per hour is not uncommon.

Temperature has a great influence on the viscosity of water, and this affects the rate of sedimentation. The rate of settling of floc at 30°C is 2.3 times the rate at 0°C. Allowances should be made for this factor, particularly in cold climates.

The sedimentation period is expressed in different ways. The " detention period " is the time computed by dividing the volume of the tank by the

rate of flow through the tank. This is a theoretical figure, for water seldom, if ever, moves through a tank in a perfectly uniform manner, and as a uniform mass. A determination of the "flowing through" period can be made under any given set of conditions by adding concentrated dye or salt for a brief period to the incoming flow, and subsequently measuring its appearance in the effluent. The efficiency of any given tank, under any particular condition of flow, is computed by dividing the "flowing through period" by the "detention period". This factor, called "efficiency of displacement", should not be less than 30 %, within the normal range of operating conditions. Normally, in a horizontal-flow basin, provision is made for a four-hour detention period.

The depth of a horizontal-flow sedimentation basin determines the time required for floc to be deposited on the bottom. Depth is not a very critical factor. A common computation is to multiply the settling rate of the floc by the design detention period, and to add additional depth equal to the anticipated maximum thickness of the deposited sludge layer, usually about 2 ft (0.6 m). The design of such a tank should provide quiescent space in the bottom where sludge is not subject to scour. The depth of a vertical-flow tank is related to design factors other than those already mentioned, and must be proportioned to such operating features as depth of sludge blanket and the means provided for concentration and removal of sludge.

The surface area of sedimentation basin is generally established by the "surface overflow rate", which is obtained by dividing the design rate of flow by the surface area. This gives a linear rate, which is expressed in various units, e.g., millimetres per second or feet per hour; in American practice the surface overflow rate is often given as gallons per square foot per day. For horizontal-flow basins, the surface overflow rate should not exceed the equivalent of 5 ft (1.5 m) per hour, and this only under conditions where a rapidly settling dense floc can be maintained invariably. A suitable figure is more nearly half of this value. With vertical-flow sedimentation tanks, particularly those operating on a solids-contact principle, i.e., where the floc-bearing water passes upward through a sludge blanket, the surface overflow rate is normally greater, in the order of 10-12 ft (3.0-3.6 m) per hour.

The theory underlying the solids-contact sedimentation tank is described by Degrémont (1960) and by Nordell (1961). Its essential feature is that the coagulated water, after a flocculation period of 10-15 minutes, is introduced into the bottom of a tank and flows upward through a blanket of precipitated floc at a continuously decreasing velocity. The level at which the upward velocity of the water is equal to the settling velocity of the precipitate constitutes the upper surface of the sludge blanket. Above this level, any flocculant particles remaining tend to settle downward. Sufficient depth must be provided above this level to ensure that fluctuations in flow or in the volume or density of the sludge will not result in solid particles

being carried over the outlet structure. The portion of the tank occupied by the sludge blanket through which water is passing is called the active zone. In association with this, there is a concentration zone, in which the sludge is quiescent, free from upward currents. From this zone, sludge is drawn off either continuously or periodically to keep the sludge blanket volume within reasonable limits. There are a number of variations in designs utilizing this principle. It is greatly favoured by equipment manufacturers who can adapt it to a self-contained, pre-fabricated unit. Extravagant claims of efficiency should be viewed with suspicion, and the minimum volume of the settling basin, excluding the flocculation zone, should provide not less than a one-hour detention period, at the maximum rate of flow.

The principal purpose of sedimentation is to remove a high proportion of suspended solids before the water passes to the filters. This relieves the filters from an otherwise heavy burden, and increases the length of filter runs between periods of back-washing. Efficient settling considerably reduces the cost and difficulties of filtration. It is important that at every step coagulated water should be treated gently to avoid breaking up floc. Hydraulic transitions at ports, channels, weirs and other structures should never introduce velocities high enough to destroy floc once formed. The effluent from sedimentation tanks should preferably be drawn off at the surface over a long weir, or series of weirs. The effluent should contain a minimum of visible floc, and the turbidity of the water between floc particles should be kept below 10 units; as low as 5 units if possible.

Filtration

Filtration is the passage of water through a bed of granular material, usually sand. The object of filtration is to remove all flocculant or particulate matter, bacteria, cysts and ova of intestinal parasites. The theory of filtration and the design of filters are complex. For detailed treatment of the subject, reference is made to Fair & Geyer (1954) (chapter 24). There are three general types of filter: slow sand, rapid sand and diatomaceous earth. For milk processing plants, rapid sand filters are the most common type, but diatomaceous earth filters have a useful application in many situations. Rapid sand filters may be of either the gravity or the pressure type. Pressure filters have two drawbacks: first, their operation cannot be readily observed and in case of trouble many of their parts are relatively inaccessible; and secondly, their space requirements are not as favourable as those of gravity filters.

The size and uniformity of the granular particles determine to a considerable degree the performance and efficiency of a rapid sand filter. Filter sand is often described by its effective size and uniformity coefficient. The effective size is the effective diameter, expressed in millimetres, of the theoretical sieve opening that would pass 10 % of the weight of sand under

examination. To determine the uniformity coefficient, it is further necessary to find the effective diameter of the theoretical screen opening that would pass 60 % of the weight of sand under examination. The ratio of this diameter to the effective size is the uniformity coefficient. A commonly used specification is that filter sand should have an effective size of greater than 0.45 mm, and a uniformity coefficient of less than 1.5. British practice describes both particle size and uniformity in terms of the sieve meshes that will pass and retain the total weight of the sand. A common British specification is that a filter sand shall pass a 16-mesh and be retained on a 30-mesh sieve, the meshes used being in accordance with B.S.410 1943 (Institution of Water Engineers (1961), p. 517). If one were to assume a statistically probable particle-size distribution, this would be equivalent to an effective size of about 0.6 mm, and a uniformity coefficient of about 1.2.

Rapid sand filters are normally operated at a uniform rate. As the filter begins to clog with retained foreign matter, additional force or head is applied to maintain a constant rate of flow through the filter. In practice, a filter is commonly designed to require a loss of head of about 1 ft (0.3 m) immediately after cleaning, and to provide up to about 12 ft (3.6 m) potential loss of head. Filters are generally washed when the loss of head exceeds about 9 ft (2.7 m). The rate of filtration is expressed as a linear velocity, commonly (in American practice) as volume per unit of area per unit of time. A common rate of filtration is 2 gallons (US) per square foot per minute, which would be expressed in British practice as 16 ft per hour, or in metric units as 4.8 m per hour (1.33 mm per second).

Rapid sand filters are cleaned periodically by back-washing them with filtered water, often in combination with mechanical or compressed air agitation, the wash water being led off to waste. The agitation produced must be sufficient to separate the sand grains and to scour them against each other, but the velocity of the back-wash must not be so great as to carry away the sand. The velocity of back-washing is dependent principally on the size and density of the granular material and the temperature (i.e., viscosity) of the water. Ideally, the sand grains should be lifted sufficiently to result in an expansion of the sand bed amounting to 120 %-165 % of its operating depth. The rate of wash is expressed as a linear velocity, a common figure being 24 inches per minute (10 mm per second) where auxiliary agitation is not used. In case mechanical rakes, hydraulic jets or compressed air are used, the back-wash velocity is ordinarily reduced to a value of between 50 % and 75 % of the rate mentioned. Air scour generally proceeds at a rate of 3-5 cubic feet of air per minute per square foot of filter surface (15-25 litres per second per m²).

For proper operation, rapid sand filters, whether of the gravity or pressure type, should be equipped with instruments to indicate the rate of flow during filtration, the loss of head through the filter, and the rate of flow during back-washing.

Softening

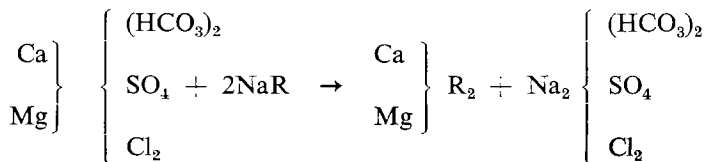
The operation of a milk processing plant is greatly simplified if its water supply is soft, that is, relatively free from compounds of calcium and magnesium, particularly their carbonates and bicarbonates. Not all the water used in a milk plant needs to be softened. It is important that all water introduced into a milk plant be of drinking-water quality (reference is again made to the International Standards for Drinking-Water in this respect), but a certain portion of the water may be used without special treatment for softening.

Nordell (1961) lists (p. 179) some of the difficulties that can be expected in a milk plant using hard water. In addition to forming scale in boilers, water heaters, piping and fixtures, hardness reacts with caustic compounds used in bottle washers to form a scale which clogs the recirculating system — pumps, pipes and nozzles—and forms unsightly deposits on the bottles. It is exceedingly troublesome in pasteurizers, especially of the high temperature type. It causes trouble in can washers and leads to the formation of milk stone.

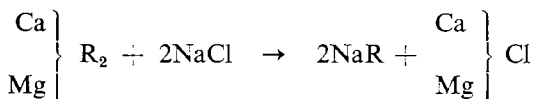
Softening is not so important in such processes as cooling, lavatory use and general plant use, e.g., floor washing, vehicle washing and the maintenance of grounds.

There are a number of processes for softening water. The two principal methods are by cation exchange (zeolite) and by precipitation with lime. The lime or lime-soda process is not used frequently in milk plants. For the details of this process, reference is made to Fair & Geyer (1954), Nordell (1961) and Degrémont (1960). Hoover (1946) has also published a very complete description of lime softening.

The sodium cation exchange, commonly called zeolite, process consists of substituting a sodium for a calcium or magnesium cation. In practice, hard water is passed through a bed of granular zeolite, the calcium and magnesium being retained and an equivalent amount of sodium being given up in exchange. Using the symbol R to represent the cation exchanger radical, the softening process can be written as follows:



The reaction is reversible, and a zeolite bed can be regenerated by introducing a solution of sodium chloride, leading to the following:



Sodium cation exchangers usually consist of a metal tank or vessel containing a bed of zeolite from 2 ft (0.60 m) to 8 ft (2.4 m) thick with necessary control fittings. Hard water is passed through the unit until the ability of the zeolite to soften the water is exhausted. The zeolite is backwashed to clean and hydraulically regrade the bed, and a solution of sodium chloride is introduced to regenerate the material. The exchanger is then rinsed free of the soluble by-products and excess salt, and returned to service.

Within limits, the ability of a bed of zeolite to soften water is dependent upon the amount of zeolite in the unit rather than upon the rate of flow. Nordell (p. 412) lists seven natural zeolites, each having slightly different exchange characteristics. In addition there are a number of synthetic cation exchangers, which fall into two general types (the resin type and the carbonaceous type) and which have an exchange capacity up to 9 or 10 times greater than that of natural zeolites. For each zeolite bed there is a more or less constant weight of hardness which the bed can remove between regenerations. The volume of water that can be softened in one cycle is therefore in inverse ratio to its hardness. In practice, a greater efficiency is obtainable if the full theoretical capacity of the bed is not exhausted, in other words, the bed should be regenerated while it still has a considerable exchange capacity. Similarly, in regeneration it is more efficient to interrupt the reaction before regeneration is complete.

The rate of flow through a softening unit is normally related to the volume of exchange material. Degrémont (1960) (p. 256) states that the average hourly output should be from 15 to 20 times the volume of zeolite, and that the maximum hourly output should not exceed 25-40 times the volume of zeolite. This provides an average contact period of 3-4 minutes, with a minimum contact period of 1.5-2.4 minutes. Care must be taken to distribute the incoming water evenly over the entire cross-section of the column, and to avoid any jetting action which may produce hollows in the surface of the sand.

Sodium chloride (common salt) is ordinarily used for the regeneration of the ion-exchange material. Salt contaminated with even traces of iron should never be used. With most zeolites, sea-water can be used for regeneration, but it must be coagulated, filtered and chlorinated before use. Other salts that can be used, if cheaply available, are sodium nitrate, potassium nitrate and potassium chloride. Sodium sulfate can be used, but only in the form of a very weak solution to avoid precipitation of calcium sulfate. The theoretical weight of salt required for regeneration is about $\frac{6}{7}$ the weight of hardness removed. The actual amount required under practical operating conditions is from 2.5 to 3 times the theoretical figure, or from 2.14 to 2.55 times the weight of hardness removed.

In regeneration, the volume of regenerating solution should be at least equal to the volume of the zeolite. The strength of the brine solutions actually applied to the bed, which includes injection water, is usually

10 %-12 % for natural or synthetic zeolites; 5 %-15 % for carbonaceous types; and 15 %-18 % for high-capacity resins. The time required for regeneration varies with the type of exchange material; Degrémont specifies from 30 to 60 minutes.

After the application of brine, the exchanger bed must be rinsed clean of residual sodium chloride and of the calcium and magnesium chlorides formed during regeneration. Rinsing is usually carried out at a rate equal to about one-third the wash-water rate, and for a period of about ten minutes. A bed should not be over-rinsed as this will result in a loss of useful exchange capacity.

Removal of Iron and Manganese

The commonest form in which iron is found in water supplies is as ferrous bicarbonate ($\text{Fe}(\text{HCO}_3)_2$). Its solubility increases with an increasing free carbon dioxide content of the water. It is frequently found in deep well water which has not come into contact with the air. Iron may also occur as ferrous sulfate, or, in surface waters, in organic combination (chelated iron). Ferrous bicarbonate is readily removed by aeration, sedimentation and filtration. Aeration removes considerable amounts of the carbon dioxide from the water, and adds oxygen, which converts the ferrous bicarbonate to ferric hydroxide, an insoluble flocculent material which normally settles rapidly and which can be removed by filtration. Nordell (1961) has shown that with aeration the oxidation reaction proceeds best at a pH of 7.0 or above. It is possible to oxidize ferrous bicarbonate to ferric hydroxide by adding chlorine. This reaction can be carried out at a lower pH, as low as 5.0 in some cases. It should be pointed out that in aerating water with a low pH, carbon dioxide is driven off, which has the effect of increasing the pH without the addition of alkali. If water has a bicarbonate alkalinity of 50 or more, reduction of its carbon dioxide content to 10 p.p.m. or lower will raise the pH above 7.0.

The cation exchanger can also be used for the removal of iron. With clear, deep well waters containing ferrous bicarbonate, the iron may be removed simultaneously with the hardness by the zeolite process. It is customary practice to limit this application to waters whose iron content, as Fe, is not more than half the hardness, and to waters containing no more than 50 p.p.m. iron, as Fe. In this process it is important that the water should not have come into contact with air before passing through the water softening units, otherwise ferric hydroxide will be precipitated on and in the zeolite bed.

The coke tray is a reasonably efficient and cheap type of aerator. Three, or sometimes four, trays with perforated bottoms and filled with coke are placed one above the other, with a distributor at the top. Water trickles down through successive trays into an aerated-water basin beneath. The

usual rate of application, based on the area of one tray, is about 10 gallons (US) per square foot per minute (6.8 litres per m² per second). The capacity of the settling basin following aeration should allow for no less than 15 minutes' detention; it is good practice to provide for 30 minutes'. If iron removal by aeration is to be combined with cation exchange for the removal of hardness, the iron should be precipitated first, and the water filtered before being passed through the cation exchange bed.

The removal of manganese follows the same pattern as for iron. While many iron-bearing waters can be treated by precipitating the iron through aeration alone, all manganese-bearing waters require that an alkali be added immediately after aeration and before sedimentation. The pH should be raised to about 10.0 for efficient results. Some additional time must be allowed for the precipitation of manganese, and the tank receiving the aerated water should provide for at least 30 minutes' detention. The equipment used for manganese removal is the same as for iron removal, and the two processes can take place simultaneously.

Neutralization

The tendency of water to corrode metal or to form scale is of great interest in a milk plant as it affects three types of water systems: (1) boiler water, (2) hot water, and (3) cooling water systems. Normally milk plants operate only low-pressure boilers; if high-pressure boilers are to be used, a special study should be made to develop a suitable boiler water treatment by a qualified expert.

The principal scale-forming material in water is calcium carbonate, which is formed on the surface of heated metal by the alteration of calcium bicarbonate according to the following reaction:



The reaction is reversible so long as carbon dioxide remains in solution, but upon heating the carbon dioxide is usually driven off, and with waters containing a substantial amount of calcium bicarbonate the resulting deposits can build up very rapidly.

Calcium sulfate can also be scale-forming if it occurs in high concentrations. When cooling water containing calcium sulfate is recirculated, care should be taken to draw off and replace enough water to keep the concentration of calcium sulfate, expressed as CaCO₃, below about 1000 p.p.m. This will generally prevent a sulfate scale from forming.

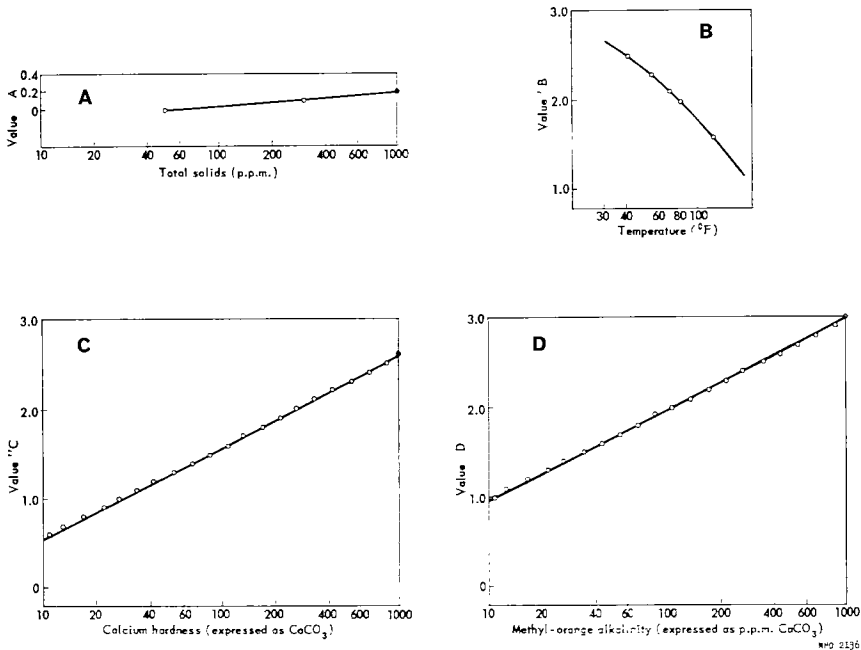
Water softened either by cation exchange or by lime softening is not scale-forming, but attention should be given to its possible corrosiveness under various operating conditions.

To judge whether a water is encrusting or corrosive, it is useful to apply the Langelier index. The index is computed from the observed pH and a

calculated stability pH (designated pHs), the saturation index being equal to pH minus pHs. If the index is zero, the water is in chemical balance; if the index is positive, the water is scale-forming; if the index is negative, the water is corrosive. For the computation of pHs, four values must be known: the total solids; the temperature to which the water will be raised; the calcium hardness, expressed as CaCO₃; and the methyl-orange alkalinity of the water. The four charts shown in Fig. 1 provide four factors, A, B, C and D, from which the value of pHs can be calculated as follows:

$$\text{pHs} = (9.3 + A + B) - (C + D)$$

FIG. 1
CHARTS FOR COMPUTING THE VALUE OF pHs *



* After Nordell (1961) (p. 287)

In using the charts, figures should be rounded off to the nearest tenth, as extreme accuracy is not significant. In practice, common sense must be used, and the index used more as a guide than as a precise calculation. Usually after treatment is instituted, test sections are inserted in the piping system and the scaling tendency is observed. If scale forms, the treatment should be modified to lower the Langelier index. It is usually desirable to treat the water to the point that a very light coating is maintained on the metal surfaces.

In applying the Langelier index, it will be noted (a) that with a water which will tend to be corrosive in use, this tendency can be corrected (i.e., the pHs can be lowered) by decreasing total solids, or by increasing the working temperature, the hardness and the methyl-orange alkalinity; and (b) that with water which will tend to be encrusting in use, this tendency can be corrected (i.e., the pHs can be raised) by increasing total solids, or by decreasing the working temperature, the hardness and the methyl-orange alkalinity. Total solids do not have a very marked effect on the stability pH. The working temperature of the water is usually fixed within a few degrees by the conditions of use. Consequently the only two factors that can be varied in a practical way enough to have a marked effect are hardness and alkalinity. Carbon dioxide accelerates corrosion in waters of low pH and low alkalinity, and this tendency is stronger at higher temperatures. Waters containing sulfur may produce metal sulfides, corroding the surfaces. It is good practice to chlorinate sulfur waters, after aeration, to oxidize or precipitate the sulfur.

Considerable savings can be effected by re-use of treated cooling water, either by recirculation through cooling towers or heat exchangers, or by using it for other purposes. Cooling water, which is already partially heated, can be used after additional heating if necessary, for washing cans, bottles or other equipment, or in other plant processes. Savings result not only in the costs of production and treatment of the water, but also in the costs of treating the plant wastes. Any reduction in the volume of wastes tends to lower the cost of their treatment.

It is possible with waters of relatively low hardness to add polyphosphates and organic boiler compounds to boiler-feed water and thereby prevent the formation of scale. Boiler compounds have for their purpose the precipitation of calcium and magnesium in a form that will not adhere to metal walls in the form of scale. The precipitate is still present, but in the form of suspended material. Nordell (1961) (p. 268) lists seven phosphates which are used for this purpose, together with tables for computing dosages. Organic boiler compounds include tannin, starch and other natural or synthetic products; when properly made and used, they are valuable in the control of scale in boilers.

WASTE TREATMENT

“ The control and disposal of wastes is of major concern to many plants in the dairy industry. Optimum reduction and utilization of wastes are essential for economic production in both small and large plant operations. Wastes which cannot be prevented must be disposed of in a suitable manner.

“ The Nation's water resources are seriously limited in some places. To conserve and protect all water resources for maximum use is mutually beneficial to the individual citizen, our ever expanding industries, and the

Nation as a whole.” (United States Department of Health, Education and Welfare, Dairy Industry Committee, 1959).

The subject of dairy wastes must be approached from two directions: the prevention of waste in so far as it affects the economic conservation or recovery of useful products, and the treatment of those wastes which cannot be economically avoided. The costs of waste treatment are high, and savings in treatment costs through the reduction of waste materials can be an important factor in deciding upon measures to be used in the conservation or recovery of usable products. The principal measurement of the strength of dairy wastes is the 5-day biochemical oxygen demand (BOD). This is the amount of oxygen used up by the wastes under standard conditions over a period of 5 days at 20°C. Wheatland (1960) reports that in a factory processing about 25 000 gallons of milk per day, careful attention to conservation and recovery reduced the 5-day BOD of the waste waters from 1420 to 730 p.p.m. and the daily discharge of BOD from 826 lb. to 446 lb., equivalent to a saving of some 346 gallons of milk. Morgan & Baumann (1957) found in two American plants that supervised waste control reduced the average 5-day BOD discharged per 1000 lb. of milk received from 3.39 lb. to 1.83 lb. in one case, and from 1.53 lb. to 0.95 lb. in the other, the reductions being 46% and 38% respectively. The economic implications in these and similar cases are not insignificant nor trifling.

Waste Prevention

There are a number of processes in the milk and milk products industry which may contribute putrescible milk solids to the drainage system of the plant. These can be classified as:

- (1) reception, cooling and storage;
- (2) heat treatment and bottling of fluid milk;
- (3) butter-fat separation and handling of cream;
- (4) cheese manufacture;
- (5) butter manufacture;
- (6) condensing;
- (7) milk drying;
- (8) ice cream manufacture.

In each of these processes the regular methods of washing and cleaning give rise to liquid wastes containing milk solids and cleansing agents, but there are opportunities to reduce wastes. Good management and efficient operation calls for a detailed analysis of waste potentials in each process.

Reception

Milk is received, either in cans or in tank vehicles, weighed, cooled, and pumped into holding-tanks pending further processing. There are two chief sources of waste in this process: spillage and inadequate drainage of cans.

Spillage may result from carelessness in emptying cans into the receiving hopper or weighing tank. The proper installation of splash guards reduces the possibility of wastage at this point and careful instruction and supervision of the handlers is an effective measure. Spillage may also result from over-filling the receiving tank. This may be controlled by a suitable system of alarms or indicators, and by providing adequate capacity in outlet lines and pumps to handle the maximum rate of delivery. To reduce losses represented by milk left in the cans, sufficient time must be allowed for drainage. Milk continues to drain from a can after it is moved away from the receiving hopper. Can washers can be fitted with a drain pan at the entrance point, and a large part of the residual milk can be collected there. A volumetric rinse can also be used on each can, with about 3 oz (100 ml) of water being sprayed under pressure into the can. These washings can be collected and used for animal feeding, and a reduction can thereby be made in the wastes to be treated. By a combination of these methods it is possible to reduce receiving wastes by more than 50 %.

In the handling, cooling and storage of milk incident to its reception, losses may occur from leaks and drips in pipes and pumps, from overflows and spills, and from inadequate drainage of equipment before washing up. Leaks and drips result from damaged or poorly assembled fittings, and the use of equipment that can be cleaned without disassembling tends to reduce such wastes. It is not possible to reassemble equipment once it is put in use, so it is advisable to mount all pipes and fittings in locations where drip-pans can be placed beneath to catch the milk. Collected drippings can be used for animal feeding and kept out of the plant waste system.

To prevent overflowing of tanks and vats, these should be watched carefully, and if possible automatic controls should be installed—as, for example, float controlled valves. Where necessary, indicators or gauges should be installed to enable operators to verify liquid levels. Spillage is nearly always due to carelessness, and can be reduced by appropriate instruction and close supervision.

Heat treatment and bottling

The equipment used for pasteurization or other heat-treatment of milk usually contains a considerable surface area and after use there is a correspondingly great amount of milk adhering to these surfaces. Provisions should be made for drainage from all units, and sufficient time should be allowed for drainage to be complete. Piping should be pitched to drain, and the drainage should be collected either for use in a product or for animal feeding. It is good practice to spray-rinse equipment with a small amount of water and to collect the rinsings for use as animal food. By keeping all milk drainage and concentrated rinsings from the plant drainage system a significant reduction can be made in the load on the waste treatment plant.

When milk is cooled, either after heat-treatment or for storage, it is not uncommon for it to freeze on the cooling surfaces, and this can represent a significant loss of milk, and an additional load on waste-treatment facilities. These losses can be minimized by proper design and careful control. It is good practice to use a refrigerant of which the temperature is not below the freezing-point of water.

Cream separation

The practices described for pasteurizing equipment should also be applied to separators and their auxiliary equipment. Special consideration should be given to the drainage and rinsing of equipment used for cream, and such equipment should be steamed to remove residual butterfat and cream.

Cheese manufacture

This operation can be a major source of BOD in the plant wastes. Whey and cheese washings have a high BOD, and their conservation has a material effect on the cost of waste treatment. Any significant escape of these materials to the plant drainage system is costly. Whey vats and pans should be carefully watched to keep the liquid at a level safely below the rim, and whey pumps should be of adequate capacity and mounted in such a way that they do not become air-bound. Cheese hoops should be filled in the vats, and suitable containers should be installed beneath the presses to prevent the press liquor from entering the drain lines. Cheese curds spilled on the floor should be swept up and saved for animal food, and not washed into the sewer.

Recommended methods of waste prevention

The US Department of Health, Education and Welfare, Dairy Industry Committee (1959) gives 38 suggestions for effective waste prevention, applicable to all types of milk processing; they are as follows:

- (1) Adopt and maintain a definite waste prevention programme. Waste prevention committees and group discussions will help make employees "Waste Prevention Conscious."
- (2) Instruct plant personnel in the proper operation and handling of equipment.
- (3) Make a thorough study of plant operation to determine where losses occur.
- (4) Provide ample equipment, especially for receiving, cooling, and storing, to take care of maximum volumes so that there can be no spoilage due to delays in handling.
- (5) Mark all valves clearly, especially multiport, so that it is practically impossible for inexperienced help to turn the valve the wrong way.
- (6) Handle with extreme care all sanitary fittings, valves, rotary seals, and pump parts during every phase of operation to prevent marring which may cause leaks.
- (7) Provide reliable standby power so that processing can be completed as quickly as possible in case of a breakdown of the regular source of power.
- (8) Provide accurate temperature controls on plate, internal tubular, and surface coolers to prevent freezing-on.

- (9) Eliminate valves on the outlet side of internal tubular or plate heaters or coolers to avoid waste due to blown gaskets.
- (10) Install suitable liquid-level controls with automatic pump stops, alarms, or other devices at all points where overflows are likely to occur.
- (11) Vats and tanks should have well-rounded corners, be properly pitched, and be installed high enough from the floor for easy draining and rinsing into standard buckets.
- (12) Install equipment such as vats, tanks, and processing machinery designed to reduce to a minimum losses due to leaky joints, gaskets, packing glands, and rotary seals, etc.
- (13) Install all sanitary lines so that they can be drained thoroughly and pre-rinsed with a small amount of water into standard buckets. This residual material is suitable for animal feed.
- (14) Give distinctive markings to the different types of fittings on plate-type heat exchangers to avoid milk being pumped into the water side of the exchanger.
- (15) Provide and use proper splash shields on surface coolers.
- (16) Never fill cheese vats, ice-cream vats, pasteurizers, or cooling tanks to such a high level that spillage will occur when the product is agitated.
- (17) Worn-out or obsolete equipment or parts of equipment, including sanitary valves, fittings, and pumps, should be repaired or replaced. When a leak cannot be repaired during processing, buckets should be provided so that the product is not allowed to go down the floor drain.
- (18) Foam contains a considerable amount of milk solids and should be kept out of the sewer. Common sources of excessive foaming are open-type separators, splashing when filling tanks, air sucked in through leaky connexions in lines under partial vacuum, through leaky packing, and through faulty rotary seals or pumps.
- (19) Replace or repair leaky milk cans.
- (20) Provide the best possible conveyor levels and unloading facilities to avoid upsetting of cans during unloading, and maintain conveyors so that cans will not tip over.
- (21) Where permitted, use grid style (western style) dumping of milk cans. Where practical, eliminate the use of milk cans and substitute tank truck pickup on farms and between plants.
- (22) When unloading tank trucks, avoid spillage from the sanitary pipe or hose connexions. Be certain the tank is empty before disconnecting the sanitary pipe or hose.
- (23) Provide an adequate drip saver between can dumping and can washing. A product-saving pre-rinse (2 to 4 oz of water per can) should be used at the entrance to the can washer over the drip-saver pan extending for two or three drain positions. Such pre-rinsings can be used for animal feed.
- (24) Do not use a constantly running water hose in any room. Eliminate the cause of spillage, rather than just wash it away after it has occurred.
- (25) Avoid the use of hot wells for preheating because of the danger of filling them too full or of their boiling over. Use regular plate, tubular, or surface heaters. If hot wells must be used, equip them with liquid level controls which operate alarms or pump stops with good temperature regulators.
- (26) Operate evaporators at low liquid level to prevent boiling over.
- (27) Design all new external tube-chest evaporators with a tangential inlet from the tube chest to the evaporating space. Equip all coil or calandria evaporators with efficient entrainment separators. So-called splash disks in the top of the evaporators will not do the job unless carefully operated under the rated capacity with a low liquid level and at relatively low vapour velocities.
- (28) Wherever possible, equip the condensers of evaporators with a full barometric leg so as to eliminate the possibility of spoiling products by sucking water back through the condenser into the evaporator in case of pump or power failure. A full barometric

leg will be very helpful in maintaining a steady vacuum, which again helps to reduce entrainment losses.

(29) In filling or moving cans or barrels of liquid dairy products, take extreme care to avoid spillage.

(30) Where sugar is used in the manufacture of dairy products, take care that it is not spilled on the floor and washed into the sewer. Sugar will pollute the stream just as much as will milk solids.

(31) When condensed products have been removed from vacuum pans into storage or cooling vats, utmost care should be taken that no cleaning solutions be allowed to enter the vats, thereby spoiling the product.

(32) All dust from spilled or wasted products in milk-drying operations should be scraped or swept up with the aid of a vacuum sweeper. These products should be collected and disposed of for animal feed. Water from hoses should never be allowed to flow constantly over powder-room floors.

(33) Provide a foolproof whey collection system and avoid leaks from valves and fittings on whey lines which will result in ultimate loss of whey to the sewer and in floor corrosion.

(34) Provide standby pumps for pumping whey from cheese vats to storage tanks in case of power or pump failure.

(35) Provide whey storage tanks of twice the maximum daily volume for all types of cheese and casein plants.

(36) Sweep up all spilled cheese curd particles from the floor. Do not wash them down the sewers.

(37) In casein operations, collect all casein dust and collect all fine particles with proper settling equipment or filter presses. This can be used for animal feed.

(38) In lactose manufacturing plants, evaporate lactose mother liquors and lactose wash liquids and use them for animal feed. Storage and catch basins must be available. Remove albumin or other cake carefully from the filter presses so that none is lost to the sewer.

Selection of Waste Treatment Methods

Sanitary wastes, that is to say wastes carrying human excrement, should be kept separate from the process wastes and treated or disposed of in a separate disposal system. The treatment of dairy wastes requires careful technical and scientific consideration, and it is good policy to enlist the services of a qualified expert in this field since a considerable capital outlay may be involved. The bases of design are reliable data on the volume, strength and composition of the wastes, including seasonal or process variations, and the allowable quality of the effluent from the waste treatment plant. There are several choices of treatment method, including (at present) aeration, irrigation, biological filtration (including alternate double filtration), and activated sludge. Other treatment methods are described by, for example, the American Chemical Society (1953), Eldridge (1942), and in other technical literature listed in the accompanying bibliography.

The required quality of the final effluent imposes the chief restriction on the selection of a method of treatment. In general the amount of BOD which may be discharged depends on the character of the receiving stream,

and the discharge must not impair the quality of the receiving water beyond a definite limit. In Great Britain, River Boards generally impose an "effluent standard", and ordinarily require that the effluent from a dairy waste treatment plant shall not exceed 20 p.p.m. of 5-day BOD. Where the diluting flow in the receiving stream is small an even more stringent requirement may be laid down. The final requirement, therefore, may be expressed in either of two ways, a maximum weight of 5-day BOD that may be discharged in any single day, or a maximum concentration, in parts per million, of 5-day BOD in the plant effluent. With an accurate estimate based on actual measurement of the wastes, and of the maximum waste load to be treated, the required percentage reduction of 5-day BOD can be computed. This computation may immediately rule out certain treatment processes which cannot yield the required percent removal of BOD. The remaining alternatives can then be analysed for practicability and cost, and a final selection can be made. Cost analysis should include both operating expenses and the amortization of capital. The possibility of discharging dairy wastes into a public sewerage system should not be overlooked. Municipalities may impose a charge for handling such wastes, but this may well be less than the costs of constructing and operating a separate waste treatment plant. In case sewer charges are based in part on the strength of wastes received into the sewers, a study might be made of the relative economy of partial treatment before discharge into the public sewers.

Plant waste flows fluctuate greatly during the course of an operating day. Depending on the type of treatment, it may be economical to provide a balancing tank to receive and hold peak flows for subsequent more uniform release to the treatment plant. This has the effect not only of equalizing flows, but also of mixing wastes of different character and strength, producing a more uniform loading for subsequent processes.

Aeration

The principles of aeration of milk wastes are described by Trebler & Harding (1955), who list five "fundamental facts":

- (1) Milk wastes are exceptionally easy to treat by aerobic fermentation
- (2) Where wastes contain a relatively high proportion of whey, the addition of assimilable nitrogen is helpful
- (3) By extended aeration the milk solids are aerobically digested to a considerable extent
- (4) Temperature is important; the optimum appears to be about 86°F (30°C); at 50°F (10°C) the rate of fermentation is practically stationary
- (5) It seems doubtful that milk waste aeration tanks can be operated consistently without removal of some sludge

The aeration process is similar to activated sludge treatment—a process described in any standard text on sanitary engineering. The aeration process

differs in that aeration of the sludge developed is continued until the sludge is stabilized, whereas in the activated sludge process a proportion of the sludge is withdrawn, either continuously or periodically, to separate digester units or for other disposal. In the aeration process, the cells are destroyed by their own metabolism (endogenous oxidation), thus greatly reducing the sludge volume. After vigorous oxidation, generally with air introduced through diffusers, the aerated liquor is led into a settling tank where suspended solids are removed for return to the aeration tank and the clear supernatant liquid flows to the receiving stream.

The capacity of the aeration tank is based on the weight of 5-day BOD applied and on the total daily volume of flow. Milk wastes contain very little suspended matter, except for some cheese curd and materials found in floor washings, such as a small amount of sand, milk bottle caps and other debris. It is normal practice in the aeration process to allow up to about 36 hours' aeration. Trebler & Harding (1955) report satisfactory operation with oxidation at a uniform rate for 24 hours, even where the raw waste load enters the process with extreme non-uniformity. The exact design of the aeration units does not appear to be critical, and tanks can be square, rectangular, or of horizontal or vertical cylindrical shape; they can be shallow or deep, and can be operated with uniform or variable level, or as fill-and-draw tanks. The important points are that oxygen be supplied continuously to all portions of the liquid, and that the liquid be maintained as nearly as possible at the optimum temperature of 86°F (30°C). The United States Department of Health, Education and Welfare makes the additional point that the concentration of solids in the liquor undergoing aeration should be kept below 9 %.

Aeration tank capacities are sometimes worked out in terms of the BOD loading, amounting to 20 or 30 cu. ft/lb. (1.25-1.85 m³ per kg) of 5-day BOD per day. The amount of air required in the aeration process varies with the extent of oxidation desired. Initial assimilation requires a weight of oxygen equal to one half the weight of milk solids. Complete oxidation requires a weight of oxygen equal to 1.25 times the weight of milk solids. In terms of air and BOD, the theoretical requirement is for 1.5 m³ of air per kg of 5-day BOD (24 cu. ft/lb.) for initial oxidation and 2.5 times this amount for complete oxidation. In practice, only 3 %-5 % of the oxygen brought into contact with the liquor is used in the biochemical reaction. If compressed air is applied through diffusers it is necessary, for complete oxidation, to apply an amount of air in the order of 120 m³/kg of 5-day BOD (2000 cu. ft/lb.). A great deal depends upon the design of the system, e.g., the size of air bubbles produced by the diffusers, and it has been reported (United States Department of Health, Education and Welfare, Dairy Industry Committee, 1959) that up to 5000 cu. ft of air per lb. of 5-day BOD has been required in some instances. Wheatland (1960) points out that this can be costly.

The effectiveness of the aeration process is usually expressed as percentage removal of 5-day BOD. The aeration process is capable of effecting 95 % or higher removals; it can be adapted to lower levels of purification where conditions may permit.

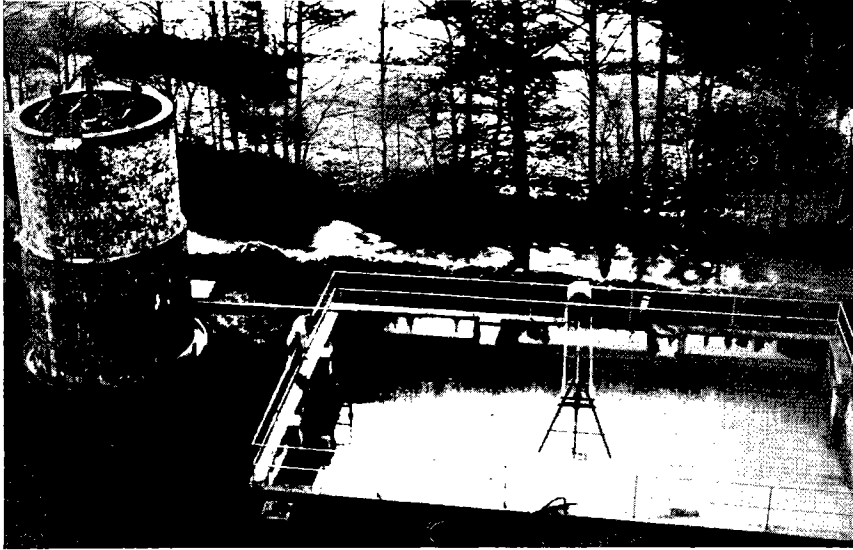
Biological filtration

The action of biological filters depends upon contact phenomena rather than on any filtering or straining action. Biological filters for milk wastes can be constructed of a great variety of materials: stone, wood, brick, coke, or any other reasonably durable substance. Biological filters depend for their effectiveness on two essential elements: a large surface area upon which a biological coating or slime can develop, and a copious supply of air to the coated surfaces. The commonest form of filter is a structure containing carefully graded stone, the pieces having nominal diameters greater than 2.5 in. (6 cm) and less than 3.5 in. (9 cm). These sizes are not critical and finer material can be used. Wheatland (1960) reports the use of metallurgical coke graded from $\frac{3}{4}$ to $1\frac{1}{2}$ in. (2-4 cm) nominal diameters. The thickness of the filter is subject to considerable variation. A common figure is about 7 ft (2 m), although filters as shallow as 4 ft (1.2 m) and as deep as 9 ft (2.7 m) have been used successfully. The size of the filter is a function of the BOD loading, and the rating is expressed in terms of weight of BOD per unit volume of filter per day. Rates normally range from 0.3 to 0.5 lb. of 5-day BOD per cu. yd (0.18-0.3 kg per m³) of filter medium per day, although higher rates are reported. In the design of biological filters it is important to distribute the liquid over the surface of the filter very evenly, and intermittently. The liquid can be sprayed from fixed nozzles, in which case an automatic siphon is used to produce intermittent application, or from rotating arms equipped with nozzles along their axes (see Fig. 2). Ventilation is important also, and is most often produced by laying the filter medium on a perforated base having a free circulation of air beneath. For the sake of good natural ventilation it is considered good practice to build the entire filter, including its under-drains, completely above ground level.

In the design of a filter consideration must be given not only to the BOD loading, but to the hydraulic flow also. The rate of application to the filter should not exceed about 160 gallons (US) per cubic yard (0.83 m³ per m³) of filter medium per day, the normal rate being two-thirds of this value. There is a maximum strength of wastes that should be applied to a biological filter, amounting to about 400 p.p.m. of 5-day BOD. For single-stage conventional-rate biological filters treating milk wastes, it may be desirable to use diluting water to keep the BOD concentration below this approximate level, otherwise difficulties will arise from ponding of the bed, due to overgrowth of biological masses. Biological filters are capable of reducing BOD by 75 %-90 %.

FIG. 2

PLANT FOR TREATMENT OF MILK WASTE WATERS BY CHEMICAL COAGULATION
(IN TANK ON RIGHT) FOLLOWED BY PASSAGE THROUGH A DEEP PERCOLATING FILTER
(ON LEFT)



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FIG. 3

GENERAL VIEW OF WASTE TREATMENT PLANT AT A DAIRY



The waste waters are collected in the tanks furthest from the camera, treated in the percolating filters in the centre, and finally settled in the humus tanks in the foreground.

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Post-filter sedimentation

Biological filtration should be followed by sedimentation. Filters periodically "unload", that is, masses of the biological growth are detached from the filter medium, and at times such material, commonly called humus, appears in considerable quantities in the filter effluent. Humus settles readily, as a rule, and a detention period of one hour usually allows for satisfactory settling and results in a clear supernatant liquid which can be drawn off over a surface weir (see Fig. 3).

High-rate biological filtration

The effectiveness of biological filtration can be improved, and the size of filters thereby reduced, by re-circulating settled filter effluent continuously with the waste being applied to the filter. Eldridge states that the BOD loadings on a high-rate filter can be four times the rate of application to a simple or conventional filter, which would be equivalent to 1.3-2.0 lb. of 5-day BOD per cu. yd (0.8-1.2 kg per m³) of medium per day. The recirculated flow can be much greater than the incoming flow, and recirculation ratios—i.e., the ratio of the incoming flow to the return flow of settled effluent commonly ranges from 1:1 to 1:10. Particularly when the recirculation ratio is low, it is considered good practice to operate the recirculation pumps in such a way that the hydraulic flow to the filters is more or less uniform. The minimum hydraulic rate should preferably be greater than 250 gallons (US) per cu. yd (1.3 m³ per m³) of filter medium at all times, although good experience has been reported with somewhat lower rates.

It is important to follow high-rate filtration with final sedimentation tanks. One of the characteristics of such a filter is its continuous "unloading". The biological growth on the filter medium is of a different nature from that in a conventional biological filter. It is thinner and very much more active, and is continually renewing itself, sloughing off the older growth. Consequently, there is a considerable amount of solid organic matter in the filter effluent. The detention period for a final settling tank is normally one hour, based on the total recirculated flow.

The efficiency of a single-stage high-rate biological filter, followed by sedimentation, ranges from about 90 % to 99 % removal of five-day BOD.

Double filtration

Double filtration—more specifically, alternating double filtration—has been gaining favour, particularly in Great Britain. In this process, the purified effluent from one filter, after sedimentation, is passed through a second filter. Wheatland (1960), in reporting on this process, points out that a percolating (biological) filter which has become partially clogged can be cleared by passing through it the effluent from another filter. By constructing two filters, and by alternating them every two weeks from primary to secondary service and vice versa, ponding could be controlled and very high

efficiencies could be attained. With filter loadings up to about 0.5 lb. of 5-day BOD per cu. yd (0.3 kg per m³) of filter medium (based on the total volume of both filters) Wheatland reports BOD concentrations in the final effluent consistently lower than 10 p.p.m., the efficiency frequently being over 99 % removal.

Digestion and disposal of solids

Although the solids resulting from the aerobic treatment of milk wastes are largely consumed in the process, it is seldom if ever possible to do away with them altogether. Some means must be provided, therefore, for their final handling and disposal. There are three general methods for disposing of sludge: lagooning, drying, and digestion and drying. Sludge from tanks used for settling raw milk wastes is very objectionable, giving rise to putrid odours, and being difficult to dry or dispose of. The sludge from a tank used to settle treated wastes, from either the aeration or biological-filter process, is better stabilized, and when dried resembles humus. Such sludge can be put directly on to sand beds for drying. In large plants it may be economical to provide a digestion tank, in which the solids are stabilized by anaerobic decomposition, after which the remaining solids are more amenable to drying and are considerably less noxious. Data on the size of digestion tanks for milk wastes are rather scanty. Morgan & Baumann (1957) mention a digester with a capacity of about 2000 cu. ft (56.5 m³) in a plant treating a waste containing up to 900 lb. (410 kg) of 5-day BOD per day. This amounts to digesting capacity of about 2.2 cu. ft/lb. (143 litres per kg) of incoming BOD per day.

Irrigation

The United States Department of Health, Education and Welfare, Dairy Industry Committee (1959) emphasizes that, where suitable land is available and where the cover crop is carefully selected, the disposal of milk wastes by spray irrigation generally presents the most economical and least troublesome method of treatment. Porous soils are the best for this purpose, such as loose loam, sand and gravelly formations. Clay soils may be unsuitable because of their impervious nature, and because clay is subject to poisoning by sodium in the wastes. Sloping or rolling terrain is the most suitable, but the gradient should not exceed about 6 %. For cover crop, shallow-rooted grasses are recommended, and the cover should be well established before the spray operation is started. The spray irrigation system may be permanently installed, or may be composed of portable piping. Irrigation-type spray nozzles are suitable, but the wastes should be screened to remove debris that might clog the nozzles. Pumps and pump sumps should be so designed that the wastes do not become septic, and the dosing schedule should be so planned that the ground does not become waterlogged. Dosage can be at the rate of 2500-6200 gallons (US) per acre (3.8-9.4 m³ per

hectare) per day. If three or four days can be allowed between applications, the rate can be as high as 25 000 gallons (US) per acre (38 m³ per hectare) per day. Some whey may be discharged with normal plant wastes, although excessive amounts of whey may damage the cover crop. It may be desirable in some instances to install sub-surface drainage to assist in removing water from the soil. Other types of irrigation may also prove more practical or more economical. With strong wastes ridge-and-furrow irrigation may prove to be more satisfactory than spray irrigation.

Record-keeping

The treatment of milk-plant wastes is relatively expensive. To protect the value of the investment, a continuing effort should be made to operate these processes at the highest possible efficiency. This involves maintaining a set of records which can be used to appraise the results being attained. The minimum records that should be kept are the hydraulic flows in each unit of the plant, and the associated 5-day BOD determinations. Flow records reveal average daily quantities and maximum or peak hydraulic loadings. Waste flow measurements are also valuable in identifying water wastage in the plant, and can be used to effect water economies. BOD records indicate organic waste loads and are essential in computing plant efficiencies. Long-term records, maintained continuously over a period of time, are necessary data for engineering design of future works, and as such constitute a scientific contribution. Records can be very elaborate, but even the very simple measurements mentioned can, with careful analysis, be of great value. The keeping and examination of plant records is the first step in good management and good economy.

REFERENCES

- American Chemical Society (1953) *Industrial wastes* (Rudolfs, W., ed.), New York, Reinhold
- Babbitt, H. E. & Doland, J. J. (1949) *Water supply engineering*, New York, McGraw-Hill
- Degrémont, A. S. A. (1960) *Water treatment handbook*, Suresnes, France [Etablissements Emile Degrémont]
- Eldridge, E. F. (1942) *Industrial waste treatment practice*, New York, McGraw-Hill
- Fair, G. M. & Geyer, J. C. (1954) *Water supply and waste-water disposal*, New York, Wiley
- Hoover, C. P. (1946) *Water supply and treatment*, Washington, D. C., National Lime Association
- Institution of Water Engineers (1961) *Manual of British water engineering practice*, 3rd ed., Cambridge, Heffer
- Morgan, P. E. & Baumann, E. R. (1957) *J. Sanit. Engng Div.*, **83**, No. SA4, Paper No. 1336 [Proceedings of the American Society of Civil Engineers]
- Nordell, E. (1961) *Water treatment for industrial and other uses*, New York, Reinhold
- Trebler, H. A. & Harding, H. G. (1955) *Sewage industr. Wastes*, **27**, 1369

- United States Department of Health, Education and Welfare, Dairy Industry Committee (1959) *An industrial waste guide to the milk processing industry*, Washington, US Government Printing Office (US Public Health Service Publication No. 298)
- Wagner, E. G. & Lanoix, J. N. (1959) *Water supply for rural areas and small communities*, Geneva (*World Health Organization : Monograph Series*, No. 42)
- Wheatland, A. B. (1960) *Treatment of wastes from milk-products factories*. In: Isaac, P.C.G., ed., *Waste treatment : Proceedings of the Second Symposium on the Treatment of Waste Waters, University of Durham, September 1959*, Oxford, Pergamon Press
- World Health Organization (1958) *International Standards for drinking-water*, Geneva
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