TECHNICAL GUIDE

K 12

J.W. FUNKE: Industrial water and effluent management in the milk processing industry

NATIONAL INSTITUTE FOR WATER RESEARCH
COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH

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FOREWORD

The systematic conservation and reclamation of water by central and other authorities are aimed at gradually increasing available supplies. However, unless continuous parsimony in the utilization of water is religiously practised by every consumer in the Republic, the problem of recurring scarcities is bound to intensify. The proclamation of 1970 as 'water year', and the programme envisaged to make the country aware of the seriousness of the problem, should contribute significantly towards obtaining the active cooperation of the public in this vitally important matter.

The dairy industry, in the same way as other food industries, is water-dependent, consuming many millions of gallons annually. According to surveys by Mr J.W. Funke and his associates at the NIWR, the amount of water used per gallon (litre) or pound (kilogram) of product, varies markedly between factories processing or manufacturing the same product. Every improvement in the efficiency of utilization of water will therefore, be to the economic advantage of the industry, and will at the same time contribute to the national water-conservation effort. This conservation aspect, together with the potential reclamation and reuse of water, should be considered when any dairy or food-processing factory is planned, particularly as the effluents from these factories carry heavy pollution loads unless positive steps are taken to reduce their solids content.

Water that comes in contact with milk, or that is used in the manufacture of dairy products, must comply with strict and definite standards of chemical purity and bacterial content, unless it is being used for cooling or steam generation, when purity requirements are less stringent.

A thorough study of the abovementioned and many other relevant and important aspects has been made by the Institute's personnel under the guidance of their enthusiastic Director, Dr G.J. Stander. Not only the information gleaned from the world literature but also that gained through extensive research at the NIWR, is presented in this guide in a well-organized and lucid manner. A copy of the guide, which is one of a series covering several industries, should find its way onto the desk of every dairy-factory manager and foreman. The technical guidance it provides will, undoubtedly, prove both useful and instructive to the dairy industry and related interests in the Republic and elsewhere.

The South African Society of Dairy Technology, dairy educationists and research workers, as well as other interested parties, welcome the publication of the guide and are indebted to the Director and the personnel of NIWR in particular Mr J.W. Funke, the panel of experts and the editor for preparing a technical guide which is not only timely but which will become of increasing value to the Dairy Industry in the future.

J.W. Claassens

Professor of Dairy Science and Technology,
University of the O.F.S. and President of the
South African Society of Dairy Technology

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

One of the most important commodities used in any food-processing industry is water which must be of the right quality. Water which comes into direct contact with milk or milk products must meet standards which are even stricter than those for a normal drinking-water supply.

The water used in milk processing leaves the plant as polluted effluent and, especially during the flush season, the amount of milk-solids flushed into the drain can reach alarming proportions.

Effluents containing milk-solids exert a strong demand for oxygen on the surface waters that receive them. Milk-solids deplete the water of oxygen causing anaerobic conditions, smell and fly-nuisance. Particularly in areas of dolomitic or shale rock strata the discharge of milk effluents constitutes a hazard as pollution of underground water may occur through cracks by channelling.

In order to protect our limited water resources, specifications have been promulgated in terms of Section 21 of the Water Act 54 of 1956 to which any effluent resulting from the use of water must conform. These are the so-called 'General Standards'.

Raw-water purification and effluent treatment cost money; these costs depend on the volume to be treated and on the pollution load carried by the raw water and the effluent. The conservation of water and the optimum recovery of by-products, which would otherwise be wasted, can largely reduce these costs.

The many diversified problems encountered with the water supply, with water conservation and with the effluent treatment and disposal have been studied in detail. This 'technical guide' has been prepared to serve as a code of practice for all those concerned with the planning, erection, management and operation of milk-processing plants.

2. INDUSTRIAL WATER MANAGEMENT

QUALITY OF WATER SUPPLY

The quality of each water depends on the nature and quantity of the constituents dissolved and suspended in it.

Natural water is never chemically pure.

Rain water contains dissolved gases such as oxygen, nitrogen and carbon dioxide.

Surface water from rivers and lakes contains, in addition to dissolved gases, small quantities of dissolved mineral salts, such as Ca^{++}, Mg^{++} or Na^{+} salts. In general, surface waters are 'soft', but owing to their high content of dissolved oxygen or carbon dioxide they are also harmful in that they promote corrosion if used without prior treatment. Surface waters frequently carry suspended matter in the form of inorganic silt or they may be contaminated with organic matter such as algae or microbial masses, e.g. fungi. Bacterial pollution is generally present.

Borehole water is water which has generally been in long contact with the geological strata from which it is being abstracted, therefore, the amount of dissolved mineral salts is usually much higher than that in surface water. For instance, borehole water derived from dolomitic areas contains high concentrations of Ca^{++} or Mg^{++} salts and therefore is 'hard'; iron, manganese, carbon dioxide, sulphates and chlorides can frequently be found in high concentrations; suspended inorganic or organic matter is usually absent. Whereas sand formations effectively filter out bacterial pollution, this is not the case in dolomitic or shale rock strata where 'channelling' of polluted water may take place over some distance. Borehole water polluted by bacterial and other means may derive its pollutants from the indiscriminate discharge of unpurified domestic effluent or night-soil; by seepage from pit privies; from industrial effluent, or from animal droppings in the catchment area of the borehole.

The first step in judging the quality of a water involves a detailed chemical analysis. There is the danger, for instance, that if the following dissolved constituents are present in concentrations higher than those given below (at ambient temperature)(1) the water will corrode iron:

Chlorides : 150-200 mg/l
Fe : 0.1 - 0.2 mg/l
Mn : 0.05 mg/l
Total dissolved solids at 105°C : 500 mg/l
Dissolved CO_2 : any concentration will cause corrosion.

Iron may also be corroded if the electrical conductivity is more than 1000 micromhos,

or if the concentration of dissolved O_2 is less than 5 mg/l,
or if the calcium hardness (as $CaCO_3$) is less than 70 mg/l.

A pH below 7 also indicates danger of corrosion. A rise in temperature will cause the corrosion rate to double with every 14 - 28°C rise (25 - 50°F). This is why the examination and treatment of feed waters for boilers is so important.

Deposit formation may be due to the presence of dirt and silt or microbial masses; scales are formed mainly by calcium sulphate, calcium carbonate, calcium phosphate, magnesium salts and silica.

WATER QUALITY REQUIREMENTS

The quality requirements for water vary not only from industry to industry, but even within a plant processing only one raw product as is the case in the dairy industry. Water quality standards, as published in the relevant literature, are seldom based on a critical examination of the needs of each of the processing steps. An investigation into real water quality requirements for each purpose within a factory complex usually reveals that high quality water, which must probably meet special standards, is required only in comparatively small quantities and that the bulk of the water supply can be of lower standards.

Where the water supply requires treatment one should bear in mind that volume is usually the greatest cost factor in treatment. Therefore, saving in costs for treating a lesser volume will offset the expenditure for the separation of suitable 'clean' spent process water for reclamation and reuse within the factory.

Water which may come into contact with products

Water may come into direct or accidental contact with the products in any of the following operations: washing of products, general cleaning of equipment, the final rinse in can and bottle washing; the cooling of pasteurizers, milk storage tanks, or canned products, or when the water is used for personal hygiene.

Generally for all usages within a food-processing plant where the water comes in direct contact with the product, only water of drinking quality is permitted, which implies that such water must be bacteriologically potable. Not only must such process or cooling water meet drinking water standards, it must also meet stricter quality requirements. The water must be soft because in any equipment in which the heating of water is involved, e.g. bottle-washing machines or plate heat-exchangers, some or all of the mineral salts in solution will be deposited as scale, which will reduce heat-transfer rates and clog pipes and jets. Deposit of scale may harbour bacterial growth which in turn makes sterilization a difficult task. Where such water has to be treated for hardness, organic conditioning compounds containing tannins, lignins or amines should be avoided since they may affect the quality of the product. Examples where such treated water could contact the product are: when it is in the form of steam used in vacreators, or accidental leakage of cooling water through, for example, pinholes in plate heat-exchangers.

The presence of iron, manganese or copper in the water supply is undesirable as it can impair taste or promote chemical deterioration. Deterioration can also be promoted by the presence of lipolytic or proteolytic bacteria.

The content of free residual chlorine should not exceed 0.3 mg/l, as higher concentrations are liable to affect the taste of milk products such as butter and cheese. If chlorinated waters come into contact with any phenolic compounds, including coal tar, bitumen or bituminous paints, etc., chlorophenols can be produced which have extremely strong medicinal odours for which dairy products have a remarkable affinity (see limit for phenols in Table 1).

Table 1 gives the standards for drinking water recommended by the World Health Organization(2), and the water quality recommended for milk processing(3,4). The drinking water standards from the South African Bureau of Standards are presently under revision.

Nitrite and nitrate in drinking water can cause methemoglobinemia. Because nitrite is regarded as about ten times as poisonous as nitrate, limitations are necessary for the two ions combined as this is more significant that a limitation on nitrates only.

TABLE 1

THRESHOLD LIMITS FOR DRINKING WATER AND FOR WATER USED FOR MILK PROCESSING

(Concentrations in mg/l, except pH, colour, taste and odour, and radioactivity)

	World Health Organization[2]		Additional limits recommended for water used in milk processing[3,4]
	Max. acceptable concentration (desirable)	Max. allowable concentration (permissible)	
Total solids	500	1,500	max. 500
pH	7.0 - 8.5	6.5 - 9.2	7.1 - 7.5
Turbidity units	5	25	
Colour (Hazen scale)	5	50	none
Taste and odour	unobjectionable	N.S.	none
Ammonia (as NH_3)	0.05	N.S.	
ABS surfactants	0.5	1.0	
Arsenic (as As)	absent	0.05	
Barium (as Ba)	absent	1.0	
Boron (as B)	absent	1.0	
Calcium (as Ca)	75	200	
Cadmium (as Cd)	absent	0.01	
Chloride (as Cl)	200	600	30
Carbon chlorofom extract	0.2	0.5	
Chromium (as Cr)	absent	0.05	
Copper (as Cu)	1.0	1.5	0.1
Cyanide (as CN)	absent	0.2	0.01
Fluorides (as F)	1.0 - 1.5*	1.0 - 1.5*	
Iron (as Fe)	0.3	1.0	0.1
Lead (as Pb)	absent	0.05	
Magnesium (as Mg)	50	150	
Mg + Na_2SO_4	500	1,000	
Manganese (as Mn)	0.1	0.5	0.05
Nitrate + nitrite (as N)	10	x	7
Phenols	0.001	0.002	
Selenium (as Se)	absent	0.01	
Sulphates (as SO_4)	200	400	60
Zinc (as Zn)	5	15	
Radio nucleides (gross beta activity)	N.S.	1,000 µµc/l	
Total hardness (as $CaCO_3$)	-	-	70 - 170

* depending on temperature

x if <u>nitrates</u> are present in excess of 10 mg/l (as N) the water may be unsuitable for use by infants under one year of age and an alternative source of supply must be found for such infants.

Fluorides occur in many natural waters; if present in drinking water in excess of 1.0 - 1.5 mg/l they may give rise to fluorosis.

Heavy metals such as iron, manganese, copper, etc. are undesirable in drinking water since they either impair taste or promote deterioration of food products.

The adverse effects of excessive hardness, e.g. scale formation or increased soap consumption, are well known; what is less known, however, is that completely soft water is often responsible for severe corrosion of equipment in the food industry unless it is made of stainless steel. A certain concentration of Ca^{++} and Mg^{++} hardness has, therefore, to be maintained to prevent damage by corrosion to items made from tinned steel, or aluminium.

As can be noted from the column indicating the recommended quality for water which is likely to come into direct contact with milk products, there are stricter concentration limits for copper, iron, manganese, chlorides and nitrates than those set for drinking water. All water used for human consumption or which comes into contact with foodstuffs must be bacteriologically safe.

Pathogenic organisms are spread by water; an index of their possible presence is the number of the coliform group of bacteria present. Non-pathogenic microorganisms may be harmful, since they may influence taste and odour, and produce slimes and bio-fouling of pipes.

The water standards lay down that: The total count of viable organisms grown on milk nutrient agar at 37°C shall not exceed 100 colonies/ml of water and preferably be under 50/ml.

The count of presumptive coliform organisms per 100 ml of water sample shall not exceed two using McConkey agar and incubation at 37°C (SABS method)(5).

Typical (faecal) coli: The water sample shall contain no typical coli per 100 ml when the test is performed in accordance with the SABS method (SABS 241).

For butter wash-water, additional requirements must be met, namely that if proteolytic or lipolytic bacteria are present, their number should not exceed 5 per ml; preferably they should be absent(6,7).

Water which does not necessarily affect the product quality, e.g. pre-rinse in can and bottle washing, external cleaning of floors, equipment and vehicles

Although reclaimed water, e.g. final rinse water overflow from can and bottle washers may be used for most of these purposes, such water should be sterilized if used as pre-rinse for can or bottle washing. Hot water, or wet steam, is more effective for cleaning a greasy surface than cold water and consequently less water is required.

Generation of steam or hot water

Boiler feed water should be free from hardness, scale-forming dissolved solids, iron or manganese; corrosive gases such as dissolved oxygen or carbon dioxide must be absent. More stringent specification limits are applicable to high-rating than to low-rating boilers and to water-tube than to fire-tube boilers. Most milk-processing plants operate low pressure boilers at pressures below 10.5 kg/cm^2 (150 lb/in^2).

Table 2 refers to suggested tolerance limits for boiler feed-water for low-rating, fire-tube boilers commonly used in food-processing industries. Limit characteristics of boiler water, however, can only be given as approximations since the requirements may vary greatly according to the type of boiler, its design, the fuel used, and its rate of output, etc. Only the manufacturer of the boiler concerned is qualified to give specific information on this subject, and should be approached before planning the boiler feed-water treatment plant.

TABLE 2

SUGGESTED LIMITS OF TOLERANCE FOR BOILER WATER FOR LOW-RATE FIRE-TUBE BOILERS UP TO 14 kg/cm^2 (200 lb/in) PRESSURE

[All units in mg/l except pH]

	Concentration
Total hardness as $CaCO_3$ after filtration	Below 5 when sodium carbonate is used] for internal treatment Below 2 when sodium phosphate is used] for internal treatment Below 20 (for external treatment)
Alkalinity (as $CaCO_3$)	200 - 300 (for carbonate control)
Na_2SO_4	At least 2.5 times the caustic alkalinity (NaOH)] to prevent caustic cracking
$NaNO_3$	At least 0.4 times the caustic alkalinity (NaOH)] to prevent caustic cracking
Na_2SO_3 excess	50 - 60 in de-aerated feed water (to prevent corrosion by dissolved O_2
Total dissolved solids	3000*

* Permitted limits for dissolved solids vary according to type of boiler. Working tolerances should be obtained from the boiler manufacturer concerned.

Cooling water for condensing of refrigerants

There are no reasons why water of highest quality should be used for cooling purposes, since concentrations of 4,000 mg/l dissolved solids and higher can be tolerated in evaporative recirculating systems without undue scale formation or corrosion, provided proper cooling-water treatment is applied. Slightly contaminated process water could be utilized as cooling water provided it is maintained free from odours. A total alkalinity of 100 - 400 mg/l, expressed as $CaCO_3$, and a pH of 7.7 - 8.3 is desirable to reduce the danger of corrosion, fouling and scaling.

With the use of treatment chemicals such as polyphosphates, tannin or amine-containing compounds to prevent corrosion and scale formation, and slimicides to prevent the growth of organic matter, water of lower quality can be stabilized and be used over a long period as cooling water, requiring only make-up water to compensate for loss by evaporation or bleed-off.

TREATMENT OF RAW WATER SUPPLY WHICH MAY COME IN CONTACT WITH THE PRODUCT

Where a milk-processing plant is connected to a local or regional authority's water supply, difficulties regarding suspended matter or bacteriological quality are usually not experienced. Many milk-processing plants, however, are dependent on their own water supply and consequently, it is compulsory for them to treat the raw water to bring it to the desired quality.

Removal of colour, turbidity and suspended solids

Flocculation with lime, alum, ferrous sulphate and other chemicals, followed by sedimentation and sand filtration effectively removes colour, turbidity and suspended inorganic or organic matter, and to a great extent simultaneously reduces the bacterial counts. The properties of the raw water greatly influence the choice of treatment method and treatment unit employed. In Table 3 an attempt is made to show which unit operation is the most suitable for a given quality of raw water. This should be of assistance in selecting the unit operations involved in a water purification process.

TABLE 3

INFLUENCE OF RAW WATER QUALITY ON CHOICE OF UNIT OPERATION FOR THE REMOVAL OF SUSPENDED MATTER AND COLOUR(9)

Raw water quality		Recommended unit operation
Suspended matter, mg/l	Colour (Hazen)	
Below 10	Below 10	Rapid sand filter (preceded by coagulation, if necessary)
Below 50	Below 100	Rapid sand filter preceded by coagulation
Below 50	Below 100	Horizontal or vertical flow sedimentation tank, preceded by coagulation/flocculation, followed by rapid sand filter
Below 100	Below 150	Floc blanket clarifier, preceded by coagulation, followed by rapid sand filter
Below 50	any	Slow sand filter

Control of bacterial pollution

The most common bactericidal agent is chlorine. Active chlorine can be applied to the water in the form of gaseous chlorine, or as calcium or sodium hypochlorite.

Turbidity, suspended inorganic or organic matter, high pH, nitrogenous substances like ammonia and albuminoid materials reduce the disinfecting properties of chlorine. Chlorination should, therefore, be applied after the removal of suspended solids in order to reduce chlorine consumption, thereby minimizing the danger of impairing taste and odour.

A simplified scheme illustrating the addition of chlorine after flocculation and sand filtration is shown in Figure 1.

Nitrogenous substances react with chlorine to form chloramines which have less sterilizing capacity than free residual chlorine. With the continued addition of chlorine, these chloramines are ultimately oxidized, and it is only when this reaction is complete, i.e. at what is called the 'break-point' that free residual chlorine can exist.

Figure 2 shows a typical break-point curve for a water containing free or saline ammonia.

The minimum contact time after the admixture of chlorine and before the water is used should be about 10 - 15 minutes, depending on conditions such as temperature, alkalinity, pH, presence of ammonia, etc.

Table 4 indicates the superiority of free residual chlorine (after break-point chlorination) as compared with combined residual chlorine (containing

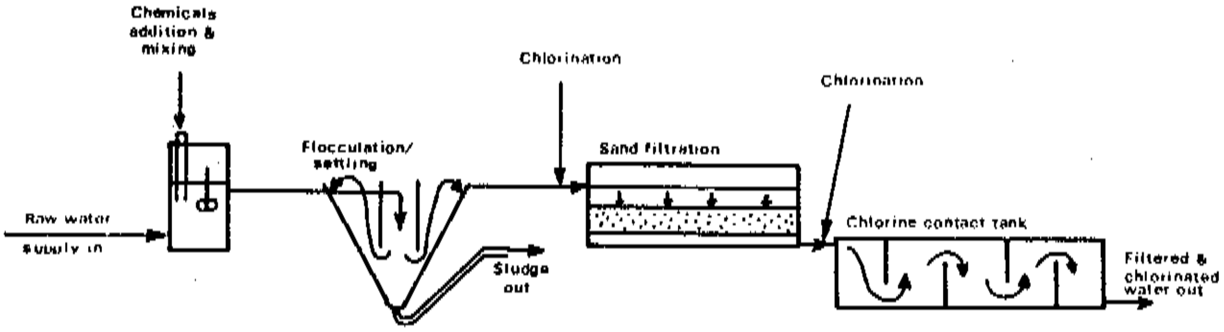


FIGURE 1

Removal of suspended solids and chlorination of a raw water supply

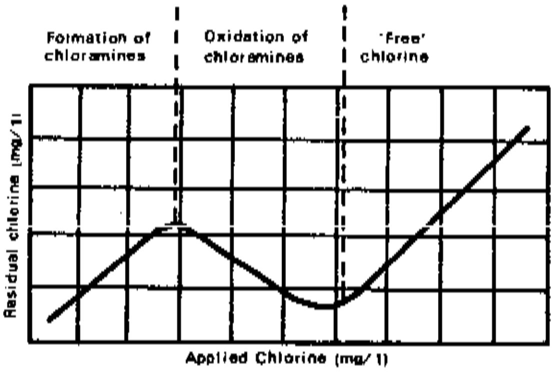


FIGURE 2

Typical "Break-point" chlorination curve for a water containing free and saline ammonia chloramines) to ensure disinfection of a drinking-water supply as shown by Cox(10).

TABLE 4

COMPARISON OF DOSAGE OF FREE RESIDUAL CHLORINE TO COMBINED RESIDUAL CHLORINE TO ENSURE COMPLETE DISINFECTION OF A DRINKING-WATER SUPPLY (mg/l)(10)

pH	Minimum concentration of -	
	free residual chlorine disinfecting period at least 10 minutes	combined residual chlorine, disinfecting period at least 60 minutes
6.0 - 7.0	0.2	1.0
7.0 - 8.0	0.2	1.5
8.0 - 9.0	0.4	1.8

Automatic equipment is available to feed gaseous chlorine at rates varying between 1.8 and 180 kg/day (4 and 400 lbs/day) in proportion to the water flow; up to 5 mg/l of free residual chlorine is recommended for water used in food processing plants which may be increased to 15 - 25 mg/l during clean-up periods. For sterilization of equipment 200 mg/l free residual chlorine are required, <u>with a minimum contact time of 10 minutes</u>. For cooling tinned and bottled milk products a free residual chlorine content of 1 - 2 mg/l should be aimed at, but every source of water needs to be evaluated on its own merits. Bacteriological tests are strongly recommended to control and confirm the sterility of tin-cooling water. When the water is chlorinated it should not be conducive to corrosion.

The use of <u>ultra-violet radiation</u> for rendering water harmless as regards bacterial contamination has the advantage that it is a process with which there is no danger of overdosing or of impairing taste and odour; also it can be operated automatically.

Ultra-violet radiation as a means of disinfecting the water supply is a simple operation that has now been accepted by a number of food-processing plants. The advantage is that this equipment, consisting of one or more UV-burners can be installed directly into the water-supply pipe. No chemicals are required and the treated water is completely free of unpleasant odours. Absence of the hazard of gas poisoning as it exists with chlorination equipment is another argument in favour of using UV-radiation as a means of rendering bacterially polluted water clean. The power consumption of an UV-element is low, e.g. 80 watts for a flow of 15,000 litre/hour (3,300 gal/hour). The useful lifetime of an UV-burner is approximately 7,000 hours (9 months) after which they should be replaced irrespective of their condition. The arrangement of the elements of a UV-burner of this type in a U-tube in the water-supply line is shown in <u>Figure 3</u>.

A limiting factor in the application of UV-radiation is turbidity. Water polluted by suspended matter or by milk-solids is not suitable for UV-disinfection.

Removal of iron and manganese

Generally surface waters are sufficiently clean with respect to iron and manganese to be acceptable; borehole water, however, does not always meet the quality requirements of a food-processing plant.

Aeration of the raw water adjusted to a slightly alkaline range, followed by precipitation and filtration, effectively removes iron and manganese. As complete precipitation of iron and manganese is not instantaneous, it is advisable to install a sedimentation basin below the aerator where the hydroxides of these metals can precipitate and settle prior to filtration. Sludge settled in this tank is removed periodically (Figure 4).

Softening hard water by the lime-soda process, preceded by aeration to supply any oxygen needed for the conversion of ferrous to ferric iron, is another effective method of removing iron and manganese.

Removal of copper or lead

Copper may enter the water from copper pipes, and lead from lead pipes, or from lead-stabilized hard PVC pipes, which are also used in drinking-water reticulation systems. Pipes made from polyethylene usually contain no objectionable heavy metals.

If present, copper and other heavy metal ions are readily removed by cationic ion-exchange resins.

Removal of taste and odour

Activated carbon adsorbs organic substances such as traces of oil, and those causing unpleasant odours and tastes. The water to be treated is either mixed with pulverized activated carbon, which at a later stage is removed by settling or filtration, or it is passed through filters of granulated activated carbon. Sand filtration prior to activated carbon treatment will reduce the volume of activated carbon required and consequently the costs.

TREATMENT OF RAW WATER SUPPLY AS BOILER FEED-WATER

In order to inhibit the dangerous effects of scaling or corrosion, some form of water treatment is almost invariably used. Where the feed-water supply is not extremely hard and the boiler pressure and boiler load rate are low, 'internal' treatment can be applied; for hard waters and for higher boiler pressures and load rates, 'external' treatment either by softening, employing the lime-soda process or ion-exchange, is to be preferred.

Since only a portion of the raw water used throughout the building requires softening, e.g. not all the wash and rinse water need be soft - two water distribution systems should be installed, one for the 'soft' water which is heated in boilers or heat-exchangers and one for water not

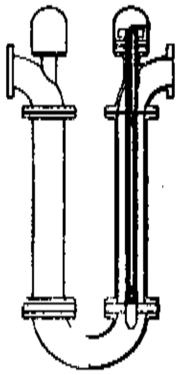


FIGURE 3

Arrangement of a 2-burner U V radiation unit in a water supply system

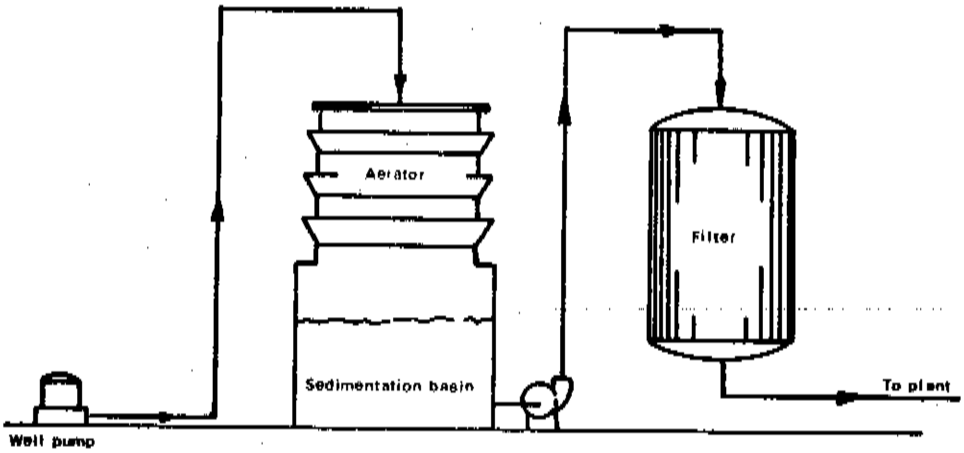


FIGURE 4

Removal of iron and manganese by aeration, settling and filtration treated for hardness, in order to save capital investment and operating costs for the unnecessary treatment of the entire water supply.

Internal treatment by chemical addition

This process, which is commonly used in low-pressure boilers (up to 14 kg/cm^2 or 200 lb/in^2), has the merit of requiring only a small amount of simple equipment. This form of treatment is, therefore, also used for 'packaged boilers' on account of the small space requirements.

Internal treatment may be effected by the addition of either sodium carbonate or sodium phosphate to the boiler water. Practically all the 'hardness' is then precipitated in the boiler. Sodium aluminate and/or organic compounds containing tannins, lignins, amines or starches are usually added to improve the mobility of the sludge produced, thereby preventing the formation of scale deposits. The use of tannins, lignins or amines, however, is not recommended for boiler water treatment in creameries, where the steam may come into direct contact with the cream (vacreator) and impair the taste of the product. The addition of sodium carbonate or phosphate in adequate excess also maintains the pH value of the boiler water at such a level that corrosion is minimized.

For each of the many types of boilers operating at a given pressure, there is an upper limit to the hardness of the feed-water which can be dealt with by internal treatment. Because of the wide variety of boiler types and pressures, it is not possible to give these hardness limits in a simple form. For most boilers operating at below 14 kg/cm^2 (200 lb/in^2) the limit for hardness appears to be between about 100 and 300 mg/l expressed as $CaCO_3$.

The chemicals may be fed by either of the following methods:

(1) either intermittently or continuously to the feed-pump section; or

(2) directly to the boiler, usually intermittently.

Addition of chemicals through the feed system can be classified as:

(1) drip feeding;

(2) intermittent feeding; and

(3) briquette feeding.

Typical arrangements for internal boiler treatment are shown in Figure 5(8).

Minimum corrosion of boiler steel is believed to occur when the pH value of the boiler water is in the range pH 10.5 - 11.5, measured at room temperature. The addition of caustic soda, sodium carbonate or tri-sodium phosphate serves to keep the corrosion of boiler metal at a minimum. Addition of sodium sulphate, to maintain the weight ratio of sodium sulphate/caustic soda at greater than 2.5 : 1, helps to prevent so-called 'caustic cracking' which may occur if only caustic soda or sodium carbonate is used.

Where electrode boilers are used, internal treatment by the addition of sodium chloride to provide the necessary conductivity is essential as well as the addition of Na_2SO_3 which acts as oxygen scavenger. Hardness must be removed to prevent scaling; this is effected by ion-exchange.

External treatment

Two methods of removing hardness have found wide acceptance, viz:

(a) the lime-soda process; and

(b) the ion-exchange process.

(a) Lime-soda process

In this process, the addition of a mixture of calcium hydroxide and sodium carbonate causes the precipitation of the calcium and magnesium salts respectively as is shown in the following reactions:

$$\underset{\text{soluble}}{Ca(HCO_3)_2} + \underset{\text{soluble}}{Ca(OH)_2} \longrightarrow \underset{\text{insoluble}}{2CaCO_3} + 2H_2O$$

$$\underset{\text{soluble}}{Mg(HCO_3)_2} + \underset{\text{soluble}}{2Ca(OH)_2} \longrightarrow \underset{\text{insoluble}}{Mg(OH)_2} + \underset{\text{insoluble}}{2CaCO_3} + 2H_2O$$

$$\underset{\text{soluble}}{CaSO_4} + \underset{\text{soluble}}{Na_2CO_3} \longrightarrow \underset{\text{insoluble}}{CaCO_3} + \underset{\text{soluble}}{Na_2SO_4}$$

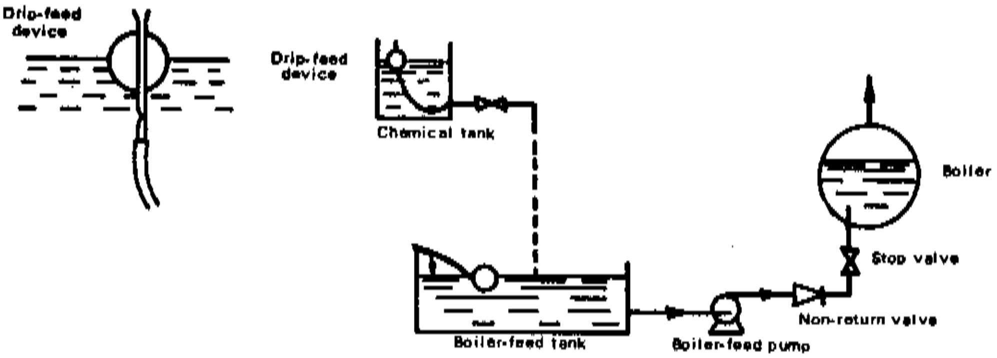
$$\underset{\text{soluble}}{CaCl_2} + \underset{\text{soluble}}{Na_2CO_3} \longrightarrow \underset{\text{insoluble}}{CaCO_3} + \underset{\text{soluble}}{2NaCl}$$

The calcium and magnesium ions dissolved in the raw water are precipitated as insoluble calcium carbonate or magnesium hydroxide, the soluble sodium sulphate and sodium chloride formed remaining in solution.

Lime-soda softening is the type of treatment most suitable for the softening of raw water with a high degree of hardness, particularly if it is chiefly due to calcium bicarbonate hardness. Where the raw water contains suspended matter, colour and organic matter, it is frequently possible to achieve simultaneously with the softening, a marked reduction of these components as they are trapped and precipitated together with the hardness constituents.

After the sedimentation of calcium carbonate the resultant softened water is filtered. Although calcium carbonate and magnesium hydroxide are only very slightly soluble under hot or cold lime-soda softening conditions, they account for the residual hardness found in lime-soda treated waters. Because hardness can be reduced to only 10 - 30 mg/l (as $CaCO_3$) this process offers no value where raw hardness is less than 50 mg/l.

Lime-soda softening requires large plant installations and strict laboratory control; large sludge volumes have to be disposed of. Where soft water of lower hardness is required, supplementary treatment by zeolite softeners proves most satisfactory.



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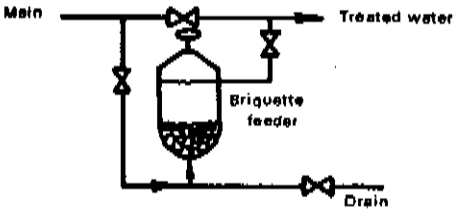

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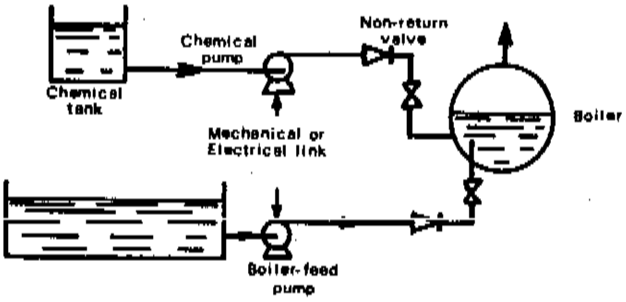

Direct injection of chemicals.

FIGURE 5

Alternative forms of internal boiler treatment

(b) Ion-exchange process

Ion-exchange softening is preferable to lime-soda softening when either of the following conditions exist:

(i) the raw water contains less than 100 mg/l of hardness expressed as $CaCO_3$;

(ii) there is difficulty in disposing of the sludge produced in the precipitation softening process.

In the ion-exchange softening of hard water the sodium ion is substituted for calcium and magnesium ions. Ion-exchange materials consist of an inert carrier bed of synthetic resin or sodium aluminium silicate (zeolite), containing an exchangeable ion, e.g. Na^+. By passing raw, hard water through the carrier, there is an exchange of sodium ions from the zeolite bed with the scale-forming calcium and magnesium ions from the raw water, the calcium and magnesium ions being selectively adsorbed onto the carrier material. The resultant treated water is completely soft.

(1) Softening

$$\underset{\text{insoluble}}{Na_2Z} + \underset{\text{soluble}}{\left.\begin{array}{c} Ca \\ \text{or} \\ Mg \end{array}\right] \begin{array}{l} (HCO_3)_2 \\ SO_4 \\ Cl_2 \end{array}} = \underset{\text{insoluble}}{\left.\begin{array}{c} Ca \\ Mg \end{array}\right] Z} + \underset{\text{soluble}}{\left[\begin{array}{l} 2\ NaHCO_3 \\ Na_2SO_4 \\ 2\ NaCl \end{array}\right.}$$

(2) Regeneration

$$\underset{\text{insoluble}}{\left.\begin{array}{c} Ca \\ Mg \end{array}\right] Z} + \underset{\text{soluble}}{2NaCl} = \underset{\text{insoluble}}{Na_2Z} + \underset{\text{soluble}}{\left.\begin{array}{c} Ca \\ Mg \end{array}\right] Cl_2}$$

The salt consumption with well-operated zeolite water softeners ranges between 1.9 and 3.2 kg (lb) NaCl/kg (lb) of hardness, expressed as $CaCO_3$ removed. This range is due to two factors:

(i) the composition of the water; and

(ii) the operating exchange value at which the zeolite is worked.

Regeneration of the resin or zeolite filter bed (see (2) above) is effected by washing out the adsorbed hardness from the filter bed with a concentrated (25%) solution of sodium chloride brine.

Some types of resin are temperature -sensitive, while others can withstand temperatures of up to 120°C (248°F). Before using any resin it is advisable to ascertain its temperature tolerance, as some resins can be permanently damaged by water temperatures in excess of 30°C (85°F).

The accumulation of colloidal material, present in the raw water, on top of the exchange bed is accompanied by a high degree of microbiological growth. This growth eventually fouls the resin bed and increases the pressure drop thus disqualifying the water for use in the food industry. Any break-through of organic matter may cause excessive foaming in the boiler. Intermittent chlorination at high dosage destroys bacterial slimes. Another way of preventing excessive bacterial growth is to flush out the resin beds at intervals of a few months. When not in operation a regenerated bed should not be left submerged for more than 10 hours.

The loss of resin caused by the regeneration processes amounts to about 5 per cent in volume per year of operation and this should be replaced to reduce loss of efficiency.

The ion-exchange installation is more compact than the lime-soda softening equipment and capital outlay and operating costs are lower; it renders a treated water of nearly zero hardness but of high total alkalinity, mostly bicarbonates, which can introduce severe corrosion problems; free CO_2, developed from the thermal decomposition of the bicarbonates may combine with the steam thereby causing heavy corrosion which will be enhanced by any air present.

Alkalinity in the boiler water steadily increases if not checked by frequent blow-downs; this high alkalinity may lead to caustic embrittlement of boiler metal.

Choice of boiler water conditioning process

In Table 5 an attempt is made to condense the information given above on boiler water treatment methods for low pressure boilers.

TABLE 5

POSSIBLE METHODS OF TREATING RAW WATER FOR LOW-PRESSURE BOILERS

(Up to 200 lb/in^2 = 14 kg/cm^2)

Method	Advantages	Disadvantages
Internal treatment by addition of chemicals	Simple and inexpensive equipment requiring little space	Frequent or even continuous blow-down required to control concentration of sludge and dissolved solids; economic application restricted to waters with max. hardness of 100-300 mg/l as $CaCO_3$; laboratory control needed for best results
Lime-soda softening	Most economical method of softening very hard waters, also removes iron and manganese	Residual hardness in treated water; large volumes of sludge to be handled; expensive equipment; proper laboratory control required
Ion-exchange	Simple and inexpensive	Uneconomical when hardness exceeds 100-150 mg/l as $CaCO_3$; no reduction in dissolved solids, therefore large blow-down required; treated water corrosive if bicarbonates are not removed

De-aeration

Dissolved gases such as oxygen or carbon dioxide in boiler feed-water are highly corrosive and must, therefore, be removed. Mechanical deaeration is the removal of the dissolved gases by heating the boiler feed-water to the boiling temperature, followed by the injection of steam into the heated water and continuously venting the mixture of steam and gases from the system. Intimate mixing of steam with the boiler feed-water is essential. Such equipment is capable of removing about 95 per cent of the dissolved oxygen and CO_2. (Figure 6).

However efficient the operation of the de-aerating feed-water heater, there will always remain a small amount of dissolved gases. De-aeration may be incomplete owing to low operating temperature; oxygen may also be introduced into the feed-water by a disturbance in operations. For these reasons it is advisable after mechanical de-aeration to introduce a continuous feed of an oxygen scavenger. The most widely used chemicals for this purpose are sodium sulphite (Na_2SO_3) and hydrazine (N_2H_4). Both chemicals react with the dissolved oxygen to render it harmless.

$$2Na_2SO_3 + O_2 \longrightarrow 2Na_2SO_4; \quad \text{or}$$

$$N_2H_4 + O_2 \longrightarrow 2H_2O \;)\; N_2$$

Na_2SO_3 concentration is controlled by maintaining a residual sulphite value in the boiler water to ensure complete oxygen removal. The testing of boiler water for residual sulphite serves as a control on heater de-aeration in plants where the oxygen content of the feed-water is not determined regularly. Any decrease in residual sulphite is an indication that mechanical de-aeration should be checked to ascertain correct heater temperature.

Experience has shown that corrosion due to dissolved oxygen usually takes place when the boiler is not in operation. Addition of an excess of oxygen scavengers to the boiler water is, therefore, essential. An excess of 60 mg/l Na_2SO_3 is recommended for feed-water which has not been mechanically de-aerated by the injection of steam.

Steam or steam condensate which has taken up oxygen is highly corrosive, and may, therefore, attack steam pipes and form rust. To retain rust particles it is strongly recommended that steam pipes leading to equipment should be fitted with dirt retention screens or strainers made from stainless steel (Figure 7), and that these strainers should be cleaned regularly. Strainers of this type are essential where solenoid valves are used.

TREATMENT OF COOLING WATER

Cooling water for condensing of refirgerants

In a system where water is used for cooling there are numerous factors which can cause or contribute to corrosion: dissimilar metals, water flow velocity, dissolved air or corrosive gases, low pH associated with low alkalinity and low total hardness, bacterial growth, or presence of sand and dirt (Figure 8).

The formation of deposits can be attributed to the presence of dirt and silt, sand, corrosion products, microbial masses, alumina, aluminium or iron phosphate, calcium carbonate, calcium sulphate, calcium phosphate, magnesium salts and silica.

In a 'stable' water which has neither a tendency to corrode nor to form scale, an equilibrium exists between the dissolved carbon dioxide, bicarbonate and calcium salts present in solution.

Fortunately a number of treatment methods and conditioning agents are available which will produce a 'stable' cooling water which is neither corrosive nor scale-forming. The two most commonly accepted indicators for the determination of the stability of cooling water are the Langelier Saturation Index and the Ryznar Stability Index.

The Langelier Saturation Index is the actual pH value of the water minus the pH when the same water is saturated with $CaCO_3$ (pHs). The calculation of pHs involves a number of variables, namely total alkalinity, calcium hardness, total dissolved solids and temperature. The pHs is calculated as (9.30 + total solids + temperature) - (calcium hardness + alkalinity). Table 6 shows how the $CaCO_3$ Saturation Index can be calculated.

A plus value for this index means a tendency to form scale; a minus value means a tendency to promote corrosion.

Whether the Saturation Index of a water is positive or negative can also be found out experimentally by stirring the water with finely divided calcium carbonate and observing whether the pH increases or decreases. This, however, is a slow process.

The Ryznar Stability Index of a water is equal to twice the pH of saturation of $CaCO_3$ (pHs) minus the actual pH of the water (2 pHs - pH). The formation of deposits will tend to occur at a stability index below 7; a water with a stability index above 6 is corrosive.

To prevent scaling by calcium carbonate in an open recirculating system, it is advisable to design the coolers so that the outlet-water temperature does not exceed 35°C (95°F). In addition, leakage of alkali into the water should be prevented.

The deposition of scale can be prevented by treating the cooling water with polyphosphate compounds or amino-compounds at concentration between 0.5 and 5 mg/l. These compounds strongly inhibit the crystallization of calcium carbonate from supersaturated solutions even at these low concentration and are, therefore, capable of preventing the formation of scale. These compounds also serve as corrosion inhibitors by interfering with the corrosion mechanism, mainly by forming a film on all metal surfaces. Combined polyphosphate/tannin compounds are often more effective in preventing scale formation or corrosion than polyphosphate alone.

Biological fouling in cooling water systems is the result of the excessive growth and development of bacteria, fungi or algae. The growth of gelatinous slimes is stimulated by the presence of nutrients, by the intense aeration in open cooling systems and by a suitable temperature range between 10 - 65°C (50 - 150°F). Certain types of bacterial deposits may

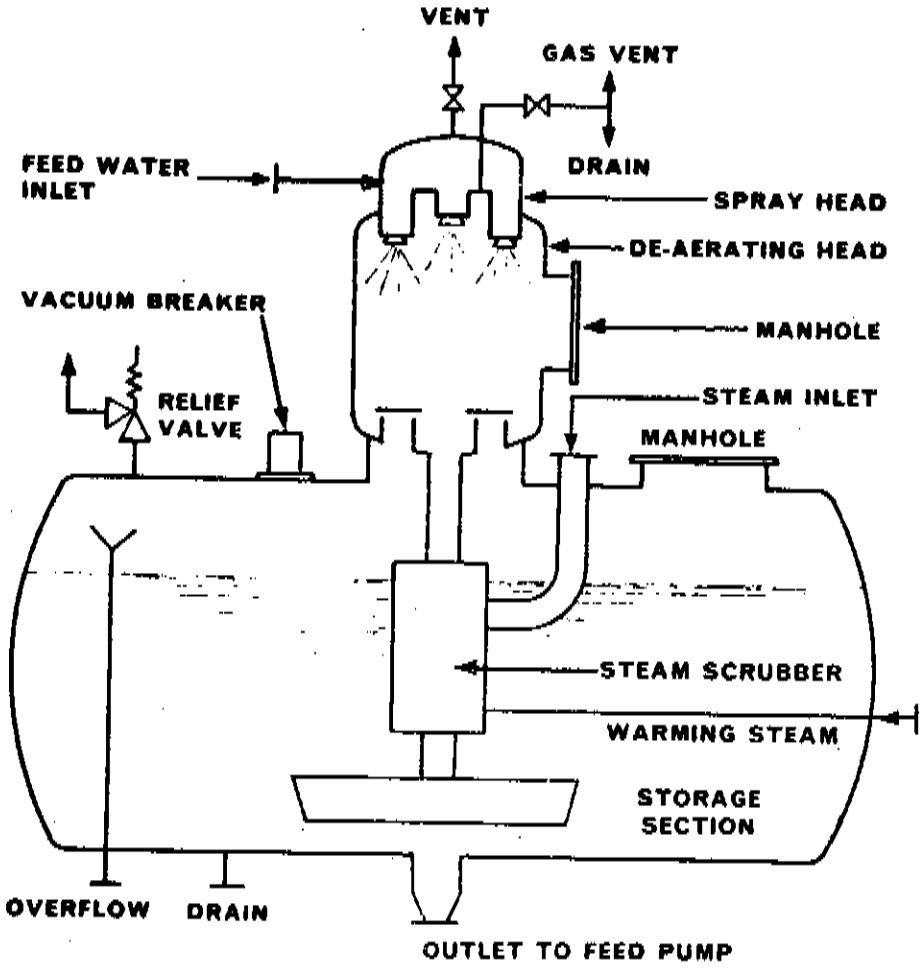

FIGURE 6

Pressure De-aerator for boiler feed water

FIGURE 7

Pipe line strainer

TABLE 6

$CaCO_3$ SATURATION INDEX (LANGELIER INDEX)[11]

(Based on the *Langelier* Formula: Larson-Buswell: Residue-Temperature Adjustments: Arranged by Nordell)

1. pHs = (9.30 + A + B) - (C + D)
   (Note. Values of A, B, C and D are obtained from tables A, B, C & D)
2. Saturation Index = pH - pHs

If index is 0, water is in chemical balance.

If index is a plus quantity, scale forming tendencies are indicated.

If index is a minus quantity, corrosive tendencies are indicated.

Example: To find the saturation index at 124°F of water which has the following characteristics: Total solids - 400 ppm; calcium hardness as $CaCO_3$ - 240 ppm; alkalinity as $CaCO_3$ - 196 ppm; and pH of 7.2. Then:

Total solids	400 ppm	= 0.16 (from table A)
Temperature	124°F	= 1.53 (from table B)
Calcium hardness as $CaCO_3$	240 ppm	= 1.98 (from lower table C)
Alkalinity as $CaCO_3$	196 ppm	= 2.29 (from upper table D)

Substituting: pHs = (9.30 + 0.16 + 1.53) - (1.98 + 2.29) = 6.72 (or 6.7)

Saturation Index = 7.2 - 6.7 = +0.5

A

Total Solids in ppm

Ppm Total Solids	
50	.07
75	.08
100	.10
150	.11
200	.13
300	.14
400	.16
600	.18
800	.19
1000	.20

B

Temperatures in degrees Fahrenheit

	UNITS				
TENS	0	2	4	6	8
30		2.60	2.57	2.54	2.51
40	2.48	2.45	2.43	2.40	2.37
50	2.34	2.31	2.28	2.25	2.22
60	2.20	2.17	2.14	2.11	2.09
70	2.06	2.04	2.03	2.00	1.97
80	1.95	1.92	1.90	1.88	1.86
90	1.84	1.82	1.80	1.78	1.76
100	1.74	1.72	1.71	1.69	1.67
110	1.65	1.64	1.62	1.60	1.58
120	1.57	1.55	1.53	1.51	1.50
130	1.48	1.46	1.44	1.43	1.41
140	1.40	1.38	1.37	1.35	1.34
150	1.32	1.31	1.29	1.28	1.27
160	1.26	1.24	1.23	1.22	1.21
170	1.19	1.18	1.17	1.16	

C

Calcium hardness expressed as ppm $CaCO_3$
(For 3 to 209 ppm $CaCO_3$, use upper table)
(For 210 to 990 ppm $CaCO_3$, use lower table)

	UNITS									
TENS	0	1	2	3	4	5	6	7	8	9
0				0.08	0.20	0.30	0.38	0.45	0.51	0.56
10	0.60	0.64	0.68	0.72	0.75	0.78	0.81	0.83	0.86	0.88
20	0.90	0.92	0.94	0.96	0.98	1.00	1.02	1.03	1.05	1.06
30	1.08	1.09	1.11	1.12	1.13	1.15	1.16	1.17	1.18	1.19
40	1.20	1.21	1.23	1.24	1.25	1.26	1.26	1.27	1.28	1.29
50	1.30	1.31	1.32	1.33	1.34	1.34	1.35	1.36	1.37	1.37
60	1.38	1.39	1.39	1.40	1.41	1.42	1.42	1.43	1.43	1.44
70	1.45	1.45	1.46	1.47	1.47	1.48	1.48	1.49	1.49	1.50
80	1.51	1.51	1.52	1.52	1.53	1.53	1.54	1.54	1.55	1.55
90	1.56	1.56	1.57	1.57	1.58	1.58	1.58	1.59	1.59	1.60
100	1.60	1.61	1.61	1.61	1.62	1.62	1.63	1.63	1.64	1.64
110	1.64	1.65	1.65	1.66	1.66	1.66	1.67	1.67	1.67	1.68
120	1.68	1.68	1.69	1.69	1.70	1.70	1.70	1.71	1.71	1.71
130	1.72	1.72	1.72	1.73	1.73	1.73	1.74	1.74	1.74	1.75
140	1.75	1.75	1.75	1.76	1.76	1.76	1.77	1.77	1.77	1.78
150	1.78	1.78	1.78	1.79	1.79	1.79	1.80	1.80	1.80	1.80
160	1.81	1.81	1.81	1.81	1.82	1.82	1.82	1.82	1.83	1.83
170	1.83	1.84	1.84	1.84	1.84	1.85	1.85	1.85	1.85	1.85
180	1.86	1.86	1.86	1.86	1.87	1.87	1.87	1.87	1.88	1.88
190	1.88	1.88	1.89	1.89	1.89	1.89	1.89	1.90	1.90	1.90
200	1.90	1.91	1.91	1.91	1.91	1.91	1.92	1.92	1.92	1.92

	TENS									
HUNDREDS	0	10	20	30	40	50	60	70	80	90
200		1.92	1.94	1.96	1.98	2.00	2.02	2.03	2.05	2.06
300	2.08	2.09	2.11	2.12	2.13	2.15	2.16	2.17	2.18	2.19
400	2.20	2.21	2.23	2.24	2.25	2.26	2.26	2.27	2.28	2.29
500	2.30	2.31	2.32	2.33	2.34	2.34	2.35	2.36	2.37	2.37
600	2.38	2.39	2.39	2.40	2.41	2.42	2.42	2.43	2.43	2.44
700	2.45	2.45	2.46	2.47	2.47	2.48	2.48	2.49	2.49	2.50
800	2.51	2.51	2.52	2.52	2.53	2.53	2.54	2.54	2.55	2.55
900	2.56	2.56	2.57	2.57	2.58	2.58	2.58	2.59	2.59	2.60

D

Alkalinity expressed as ppm $CaCO_3$
(For 1 to 209 ppm $CaCO_3$, use upper table)
(For 210 to 990 ppm $CaCO_3$, use lower table)

	UNITS									
TENS	0	1	2	3	4	5	6	7	8	9
0		0.00	0.30	0.48	0.60	0.70	0.78	0.85	0.90	0.95
10	1.00	1.04	1.08	1.11	1.15	1.18	1.20	1.23	1.26	1.29
20	1.30	1.32	1.34	1.36	1.38	1.40	1.42	1.43	1.45	1.46
30	1.48	1.49	1.51	1.52	1.53	1.54	1.56	1.57	1.58	1.59
40	1.60	1.61	1.62	1.63	1.64	1.65	1.66	1.67	1.68	1.69
50	1.70	1.71	1.72	1.72	1.73	1.74	1.75	1.76	1.76	1.77
60	1.78	1.79	1.79	1.80	1.81	1.81	1.82	1.83	1.83	1.84
70	1.85	1.85	1.86	1.86	1.87	1.88	1.88	1.89	1.89	1.90
80	1.90	1.91	1.91	1.92	1.92	1.93	1.93	1.94	1.94	1.95
90	1.95	1.96	1.96	1.97	1.97	1.98	1.98	1.99	1.99	2.00
100	2.00	2.00	2.01	2.01	2.02	2.02	2.03	2.03	2.03	2.04
110	2.04	2.05	2.05	2.05	2.06	2.06	2.06	2.07	2.07	2.08
120	2.08	2.08	2.09	2.09	2.09	2.10	2.10	2.10	2.11	2.11
130	2.11	2.12	2.12	2.12	2.13	2.13	2.13	2.14	2.14	2.14
140	2.15	2.15	2.15	2.16	2.16	2.16	2.16	2.17	2.17	2.17
150	2.18	2.18	2.18	2.18	2.19	2.19	2.19	2.20	2.20	2.20
160	2.20	2.21	2.21	2.21	2.21	2.22	2.22	2.23	2.23	2.23
170	2.23	2.23	2.23	2.24	2.24	2.24	2.24	2.25	2.25	2.25
180	2.26	2.26	2.26	2.26	2.26	2.27	2.27	2.27	2.27	2.28
190	2.28	2.28	2.28	2.29	2.29	2.29	2.29	2.29	2.30	2.30
200	2.30	2.30	2.30	2.31	2.31	2.31	2.31	2.32	2.32	2.32

	TENS									
HUNDREDS	0	10	20	30	40	50	60	70	80	90
200		2.32	2.34	2.36	2.38	2.40	2.42	2.43	2.45	2.46
300	2.48	2.49	2.51	2.52	2.53	2.54	2.56	2.57	2.58	2.59
400	2.60	2.61	2.62	2.63	2.64	2.65	2.66	2.67	2.68	2.69
500	2.70	2.71	2.72	2.72	2.73	2.74	2.75	2.76	2.76	2.77
600	2.78	2.79	2.79	2.80	2.81	2.81	2.82	2.83	2.83	2.84
700	2.85	2.85	2.86	2.86	2.87	2.88	2.88	2.89	2.89	2.90
800	2.90	2.91	2.91	2.92	2.92	2.93	2.93	2.94	2.94	2.95
900	2.95	2.96	2.96	2.97	2.97	2.98	2.98	2.99	2.99	3.00

be corrosive; fungi will attack wooden structures, and owing to the formation of deposits all types of growth will reduce heat transfer rates. Growths in cooling systems can be prevented effectively by chlorination or by the addition of slimicides into the water circuit. However, caution must be exercised in the application of chlorine to systems constructed of stainless steel. Proprietary brands of slimicides are on the market which contain chemicals such as copper sulphate, chlorophenates and mercury-organic compounds, which are highly toxic to the predominant organisms. Intermittent shock dosages of different types of slimicides are frequently more effective than maintaining a constant level of the same biocide. Where there is a possibility that carry-over from spray ponds will contaminate milk or milk products, care must be taken in the choice of slimicides and chlorination of the cooling water is the treatment preferred. The actual dose required will vary with the quality of the water; a shock dosage of up to 25 mg/l of chlorine may be applied, but the normal rate of dosing is of the order of 5 mg/l or even less.

Cooling water for cooling of condensed and sterilized milk products

The water used for tin-cooling has to be sterile as this obviates the possibility of microbial contamination. Sterilization by chlorination of the cooling water, as described above, prevents the spoilage of tinned milk products. Although a residual chlorine content of 1 - 2 mg/l should be aimed at, every source of water needs to be reviewed on its own merits. Bacteriological control as a means of confirming the sterility of tin-cooling water is strongly recommended.

Cooling water for cooling of pasteurizers or milk storage tanks

The same sterilizing treatment as that used for water which comes in contact with the product must be applied. The treatment for hardness is the same as that used for the cooling water for condensing refrigerants, except that tannins or amines should not be used as inhibitors to prevent scale-formation and corrosion as they impair the taste or odour of the product in cases of accidental leakage.

SPECIFIC WATER-INTAKE REQUIREMENTS PER UNIT OF PRODUCT

The water-intake requirements depend on the following factors:

(i) the lay-out of the milk-processing plant;

(ii) the type of equipment in use;

(iii) the application of clean housekeeping measures; and

(iv) the extent to which water is conserved and reused.

During surveys into the water and effluent situation in the milk-processing industry in South Africa, carried out by the National Institute for Water Research during the 1963/64 season and later, the intake-water figures listed in the table below were established:

TABLE 7

SPECIFIC WATER-INTAKE REQUIREMENTS PER UNIT OF PRODUCT

		Lowest	Highest	Average
Milk pasteurizing and bottling plants	litres water/litre milk	1.8	10.2	4.9
	gals water/gal milk	1.8	10.2	4.9
Creameries	litres water/kg product	9	39	13
	gals water/lb product	0.9	3.9	1.3
Cheese factories	litres water/kg product	7	37	18
	gals water/lb product	0.7	3.7	1.8
Milk condenseries	litres water/litre milk	0.014	1.65	1.1
	gals water/gal milk	0.014	1.65	1.1

One fact is eye-catching - the great discrepancy between the lowest and the highest figures reported. Lower fresh water-intake requirements usually indicate better management and production control, and usually less product wastage and reduced wash water requirements. These figures also indicate that in the majority of our milk-processing plants there is still scope for improvement. A fresh water-intake of 1.5 - 2.0 litre/litre (gal/gal) milk handled for modern milk pasteurizing and bottling plants with a throughput of 180,000 - 270,000 kg/day (40,000 - 60,000 lbs) should be the target in South African dairies.

An analysis of water requirements for specific processing steps in a dairy plant in Europe, with a fresh water intake of 4 litres/litre (gals/gal) of milk processed, is given in Table 8(12). Such figures will vary from plant to plant.

It is interesting to note that more than half of the fresh water supply was used to replenish the cooling water for condensing refrigerants and for cooling the pasteurizer and storage tanks.

According to statistical data published in the 1963 U.S. Census of Manufacturers 'Water use in manufacturing'(13), the U.S. dairy industry used 53 per cent of their total water intake for cooling purposes. Where water is recirculated, the percentage of water used for cooling is substantially less.

TABLE 8

WATER REQUIREMENTS OF VARIOUS SECTIONS IN A DAIRY PLANT(12)

Percentage break-down figures

	Percentage of total water requirement
A. FRESH WATER INTAKE	
Cooling water for condensing of refrigerants	36.1
Cooling water for pasteurizing and storage tanks for milk and cream	22.2
Generation of steam and hot water	4.4
Creamery, butter washing and cleaning	10.3
Cheese factory	8.3
Bottle washing	9.9
Rinsing and internal cleaning	3.2
Houses, workshops, garages and gardens	4.9
Toilets, washrooms and showers	0.7
	100.0
B. RECLAIMED WATER = 27.8 PER CENT OF FRESH WATER INTAKE	
Milk reception, can washing	7.9
Cheese (cottage)	6.7
Bottle washing	5.2
Process room, external cleaning	4.5
Hot water for total factory	3.5
	27.8

(adapted from Milch Wirtschafliche Wegweise, 1960)

REMEDIAL MEASURES FOR REDUCING THE COSTS OF WATER AND STEAM SUPPLIES

Modification of cooling water system

From the foregoing table it can be seen that the greatest volume of water can be saved by proper management of the cooling water.

As indicated previously, cooling water for condensing refrigerants does not come into contact with products and so need only be of low quality, provided the right type of cooling water treatment is applied. Reclaimed water from other operations can be utilized.

All cooling water should be recirculated preferably over a cooling tower in order to reduce cooling water requirements. As compared with once-through cooling water, only about 10 per cent fresh water make-up is needed to replace losses by evaporation, windage and blow-down.

Evaporation losses are determined by the amount of latent heat to be removed, therefore, these cannot be reduced.

Windage losses, however, can be largely decreased by proper cooling equipment. Cooling towers fitted with spray separators virtually eliminate these particular losses. Compact induced-draft coolers as shown in Figure 8 with spray catchers requiring little space are on the market.

The use of spray ponds for cooling should be discouraged since then windage losses are excessive. In addition, the danger exists that the products will become contaminated by spray from the cooling pond.

Make-up water requirements of cooling systems which recirculate the cooling water are not only determined by the evaporation and windage losses but also by the frequency of cooling water exchanges. The blow-down rate depends on the quality of the cooling water as regards hardness and slime formation. A total dissolved solids (TDS) content of 4,000 mg/l and higher can be tolerated before bleed-off and replacement are necessary.

Figure 9 shows the outlay of a NH_3 refrigeration system with cooling water recirculation.

Cooling water used for cooling milk products must meet the bacteriological standards for drinking water. The use of once-through drinking water from the tap is waste of money. Recirculation in a completely enclosed system where there is no water loss, as in the radiator of a motor-car, is possible and should be introduced. Indirect cooling by air passed over fin-tube heat exchangers or with refrigerants like Freon or ammonia are the methods that should be applied. Where product cooling water is recirculated over an evaporative cooling tower system, sterilization of the water is essential. An air-cooled heat-exchanger is shown in Figure 10.

A malpractice frequently encountered is that more water is used for cooling the apparatus or product than is actually required. This may be caused by fluctuating water pressure in the water supply line, and by not keeping the end-temperatures under control. Controlling the temperature by a temperature recorder controller that actuates an automatic valve in the cooling water supply line can effectively reduce water-volume requirements for product cooling.

In milk condenseries cooling water is used for condensing the vapour driven off while the milk is being concentrated, and for cooling tinned milk products. Water used for both cooling purposes can be collected, recirculated for cooling over an evaporative induced-draught cooling tower and returned. Proven practice is to reuse tin-cooling water; this includes the following treatment steps:

(1) collection of all tin-cooling water after usage in a tank of adequate size;

(2) sand filtration to remove fat particles;

(3) cooling over a cooling tower;

(4) chlorination to 1 - 2 mg/l residual chlorine to ensure sterility,

(5) return to retorts as cooling water.

Sand filters have to be cleaned regularly by back-wash. The addition of fresh water is required to replace water lost by evaporative cooling. Once per week this water is discharged to be used once again as floor wash-water.

Reduction of wash-water requirements

(i) Waste prevention measures

Wash-water requirements depend largely on the amount of wasted milk products that have to be flushed into the drain. Usually the largest portion of accidental product wastage occurs when the milk is being received and in the handling and washing of cans.

Measures to reduce accidental wastage are listed below:

(a) Place milk-receiving ramp and conveyor belt on the same level to obviate the need for lifting the cans which otherwise results in spilling.

(b) See that there is a free fall from the conveyor belt to the weighing pan for the same reason.

(c) Reduce spillage by providing the weighing pan with a protective hood.

(d) Install drip-collecting trays underneath the conveyor belt on the way to the can-washing machine, and underneath the can-washer.

(e) Eliminate leaking glands and seals at pumps, valves and pipe fittings; mount plant equipment such as pipelines, pumps, churns, vats and tanks high enough to allow placing of drip-collecting pans.

(f) Install electronic and other control devices to avoid overfilling the receiving vessel (Figures 11 and 12).

(g) Install temperature controls on coolers to prevent the freezing of milk products onto coolers and freezers.

(h) Provide adequate storage tank and processing capacity to handle peak volumes of milk and milk by-products such as whey, buttermilk, etc. thus avoiding wastage and spillage.

(i) Do not overfill cheese vats; the maximum level should remain at least 8 - 10 cm (3 - 4 inches) below the rim.

(j) Prevent foaming, caused by the sucking in of air through leaks in pump suction lines, pump packings and rotary seals by seeing that these are kept in good repair.

(k) Install product-carrying pipelines in such a way that they drain to a low point where products may be removed without loss.

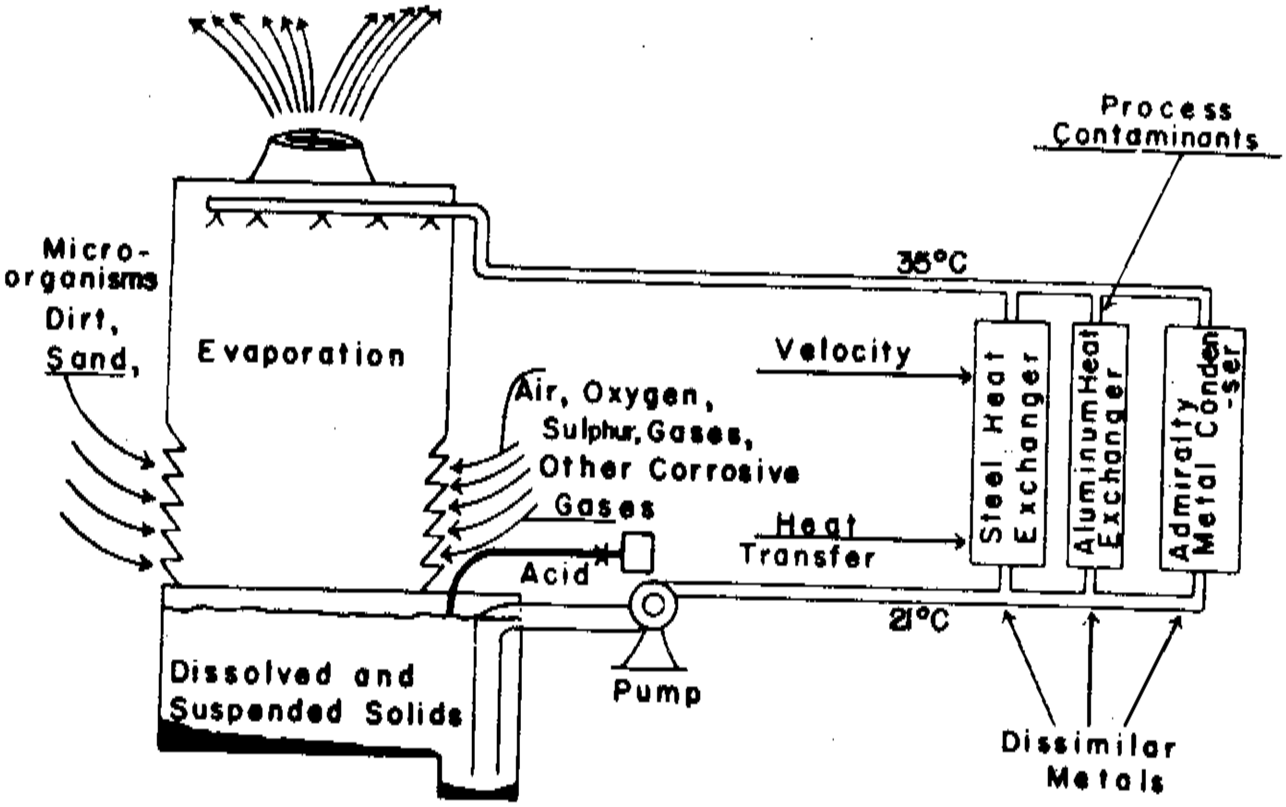

FIGURE 8

Corrosive factors in cooling tower systems

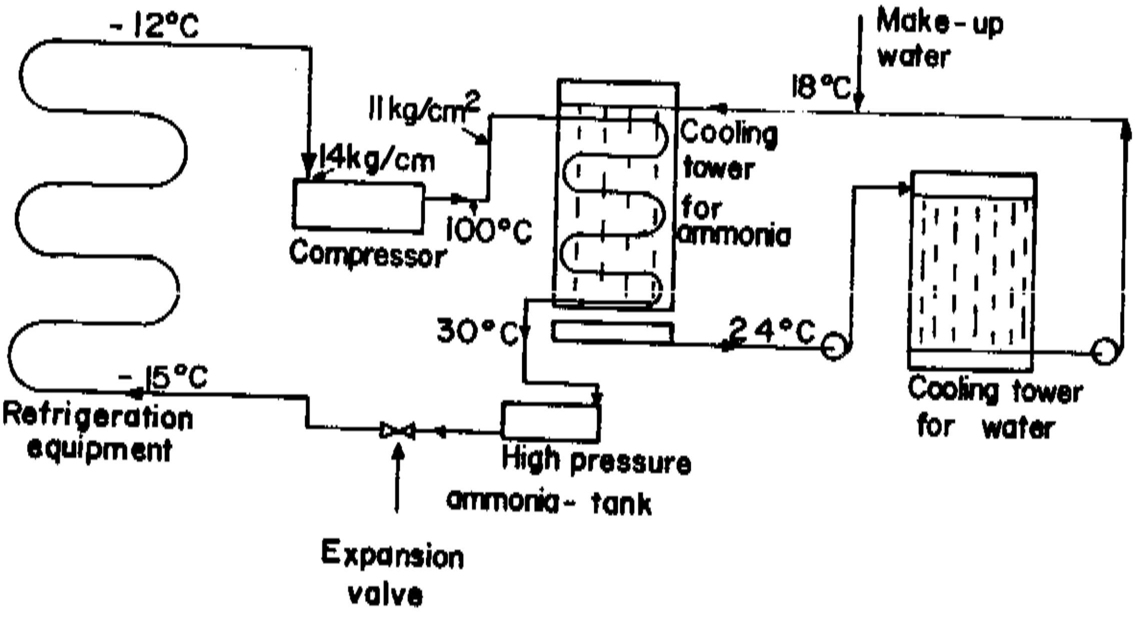

FIGURE 9

NH_3 compression-type refrigeration system with cooling water recirculation

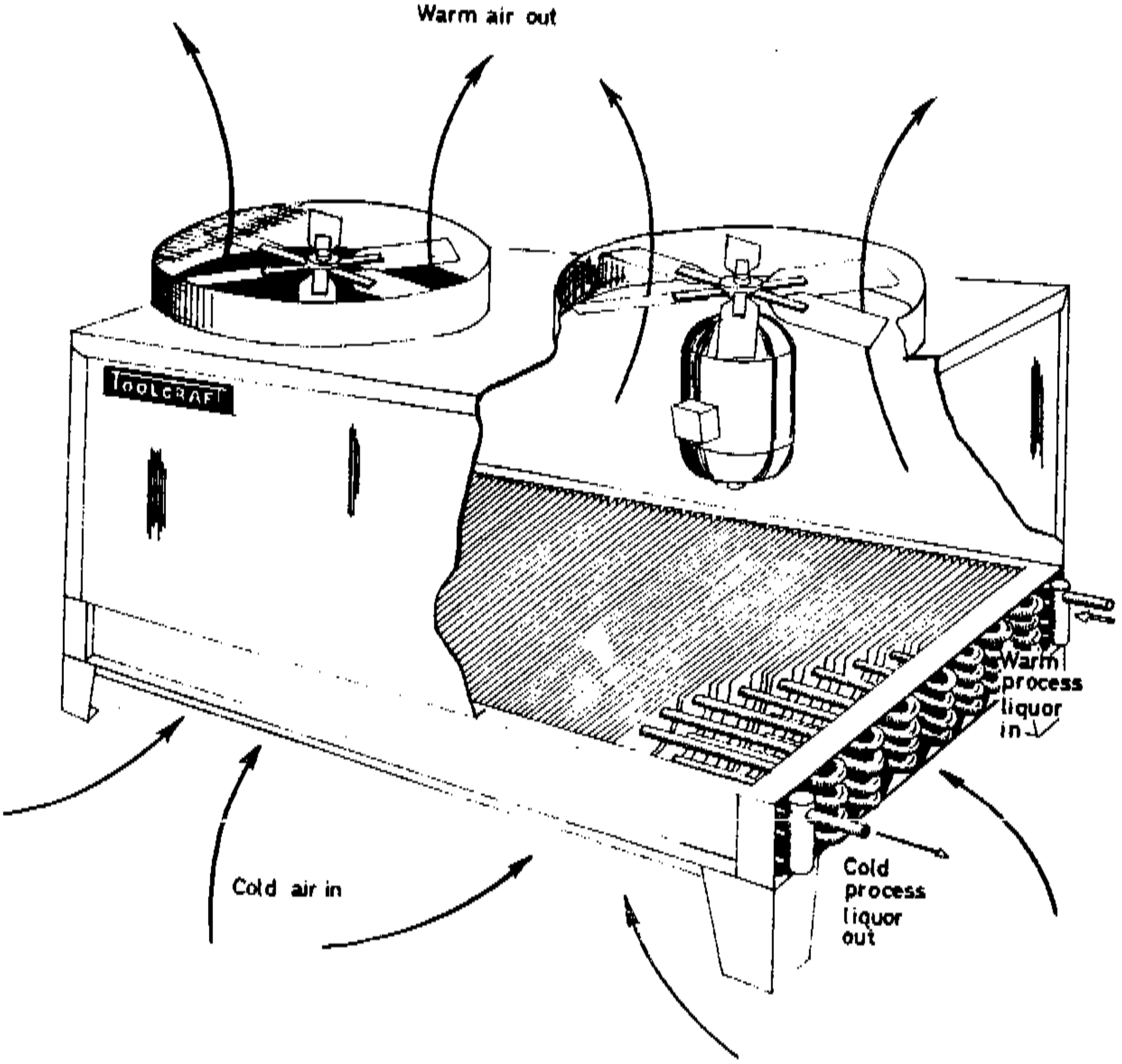

FIGURE 10

Closed circuit air-cooled heat exchanger unit with two air blowers

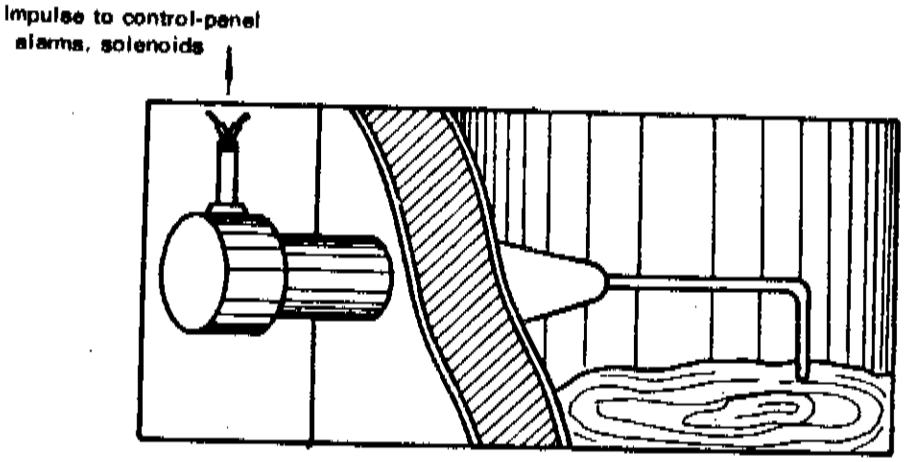

FIGURE 11

Liquid level control

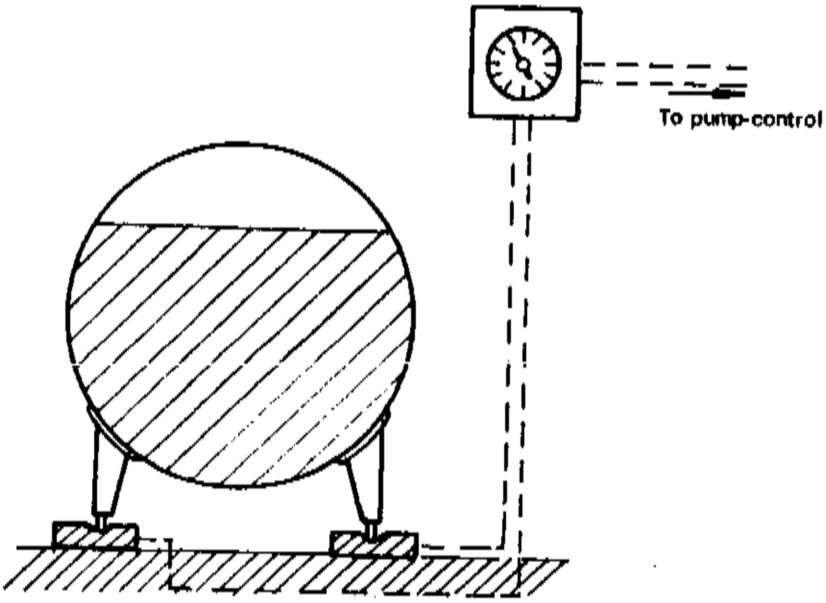

FIGURE 12

Weight-control of tanks

(l) Avoid milk tanks of poor design; the bottom should not be uneven, i.e. dented and should slope towards the outlet.

(m) Eliminate the daily manual dismantling and cleaning of equipment by in-place cleaning, wherever possible.

(n) Employ 'dry'-cleaning of floors in milk-powder factories and collect spilled products before washing down the floors with water.

(ii) Cleaning procedures

Where the floor allows it, the first cleaning step, should be dry-cleaning with squeegees. To push solid matter into the drain whether by water or by steam is a waste of water and heat energy. The floor should be covered with acid-resistant material and should slope towards a drainage channel with a pitch of not less than 1 : 50 (1/4 inch to the foot), which will make for easy cleaning.

Milk cans must be washed and sterilized as soon as possible after emptying; in large dairies this normally takes place immediately, but in small dairies some delay may be necessary in order to organize the work efficiently. For good results this delay should be under half an hour and considerably less on a hot day, otherwise milk residues become difficult to remove, and the water consumption for can-washing increases.

A can requires from half a minute to one minute to drain adequately and the drainings will represent about 1/4 per cent of the total milk intake. Provided the method of collection is hygienic, the drippings can be collected separately and used for other purposes, e.g. as animal feed.

The correct method of cleaning is to apply a cold rinse first to remove protein residues and so prevent the build-up of 'milk-stone'. This is followed by a hot rinse (which must contain detergents) to remove fatty residues. The surface of the cans is then clean and can be sterilized either by steam or with a chemical sterilizing solution.

Sterilizing of cans or vessels without preliminary cleaning and with steam alone is not only a waste of steam, but also ineffective, in fact, even harmful. Steam is not a detergent, therefore, milk residues are burnt on solidly to the walls of the cans or vessels if not removed by preliminary cleaning. The application of steam should be sufficient to raise the temperature of the walls to 82°C (180°F) at which temperature disinfection takes place in the short time available.

Hot water or wet steam are more effective than cold water for cleaning a greasy surface especially when used in conjunction with a detergent. A hot water or steam gun operating in combination with a venturi for sucking detergent into the hot water or steam is ideally suited for cleaning greasy floors. Hot water under adequate pressure should be available where it is needed. A hot water-main line avoids the necessity of having many steam connections, steam and water mixers

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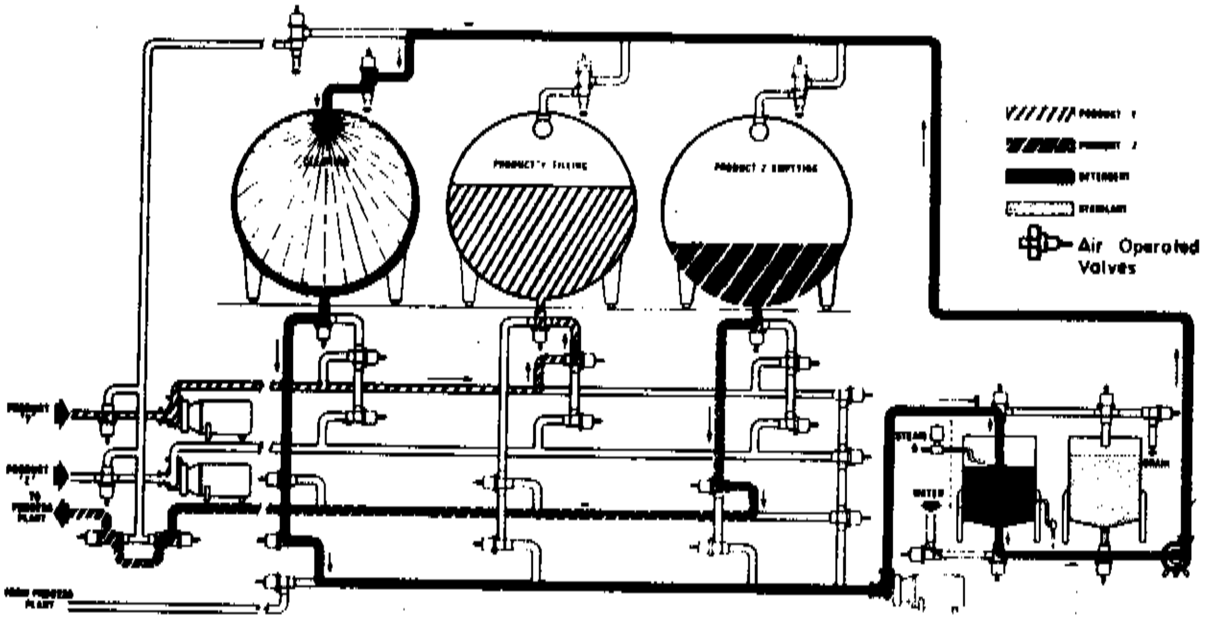

FIGURE 13

Automated control and in-place cleaning system and permits the use of a much cheaper type of hose pipe and automatic trigger-operated shut-off valves.

The daily annual cleaning mainly in smaller plants, necessitates the dismantling of every joint and consequently leads to the spillage of the product all over the floors. In-place cleaning with recirculation of cleaning solution permits the salvage of milk wastes and first-wash water at one or two points in the plant and keeps the floors dry and clean (Figure 13).

Possibly the largest source of water wastage especially in milk-processing plants, is due to hose pipes and taps being left running for hours, and even during the night. This practice should under no circumstances be tolerated. It is very easy, with a running hose strategically placed, to keep the floors clean and free from the evidence of milk spillage. Hose pipes and taps fitted with automatic shut-off valves are efffective in reducing this water wastage.

The theft of automatic valves seems a common cause of loss; placing matches or other hard objects in between the nozzle and rubber seat is another frequently-encountered method of putting automatic shut-off valves out of action. Proper supervision by the plant management and education of the labour force will reduce these unpleasant incidents and result in the saving of a substantial volume of water.

Water conservation and reclamation in bottle washing

None of the bottle-washing machines on the market was designed with the aim of conserving water. Modern bottle-washing machines require a water pressure of between 1.5 to 2.5 kg/cm^2 (21 to 35 lb/in^2). The water pressure in the main-supply line may, however, vary considerably and in some places may reach 10.5 kg/cm^3 (150 lb/in^2). It is, therefore, evident that the automatic control of water pressure in the supply to the machine will reduce the volume of water used and that wasted to the drain. For better control, a pressure gauge should also be installed.

The connection of the water supply to the drive mechanism of the bottle-washer by magnetic on/off switches is an effective means of conserving water.

Depending on the size and make of a bottle-washing machine and the size of the bottles to be washed, about 0.9 to 1.4 m^3 (200 - 300 gals) of fresh rinse water is required for 1000 bottles. Only approximately 10 per cent of the total rinse water will be reused in the pre-rinse and then go to waste - the other 90 per cent is usually drained directly into the sewer.

Fresh water which is used for the final rinse frequently carries dissolved scale-forming Ca^{++} or Mg^{++} salts. Scale formation is generally due to chemical reaction of the water with the carry-over of weak alkaline rinse, e.g.

$$Ca(HCO_3)_2 + 2NaOH \longrightarrow CaCO_3 + Na_2CO_3 + H_2O$$

Since carry-over of weak NaOH cannot be completely avoided, it is advisable in the case of such wastes, to use detergents containing polyphosphates for preventing scale formation. Where the total hardness of the fresh water is below 250 mg/l (as $CaCO_3$), polyphosphate concentrations of 0.1 to 0.3 per cent are sufficient to prevent scale-formation. The addition of hot boiler condensate as a source of polyphosphates can, in many cases, reduce the amount spent on chemicals and heat requirements.

The use of completely softened water for the final rinse should be avoided as it may cause severe corrosion.

A large portion of rinse water not used for pre-rinsing can be reclaimed for reuse in the bottle washer. A scheme developed by the Infilco Company for the reuse of the final rinse water is shown in Figure 14. The spent rinse water is collected in a pump-suction tank where it is chlorinated. A booster pump delivers the water through a diatomaceous earth filter and provides filtered chlorinated water to the rinse supply line thus completing the cycle. About 30 per cent of this rinse water is bled off and the same volume of fresh water added to counteract the build-up of dissolved solids, including caustic, and heat.

The Technical Department of the Coco Cola Corporation in Johannesburg has modified the Infilco system to suit their makes of bottle washers, by eliminating the outside pressure filter and replacing it with a 60-mesh stainless steel screen fitted into the surge tank into which the used water flows by gravity; this allows separation of incidental grease from the rinsing section (Figure 15). The recycling system is supplied with water collected from the final rinse and thus continually replaces water draining from the pre-rinse section. Fresh water is used only for the final rinse. Water intake requirements were reduced from 1230 litre (270 gals)/1000 bottles to 330 litre (72 gals)/1000 bottles, or by 74 per cent(14).

A scheme for reusing rinse water as applied at the South African Breweries at Isando is shown in Figure 16. Surplus rinse water is collected in an underground tank, to be reused after cooling as the cooling water supply to the pasteurizers.

Surplus and spent rinse water from bottle washers can also be reclaimed and used as floor wash-water by collecting it into a suitable tank, chlorinating it if necessary.

Condensate recovery from product concentration

Milk condenseries and milk powder plants are actually water producers. The vapours from the first evaporation stage can be recovered as condensate, clean enough for reuse even as boiler feed-water. The quality of the condensate varies greatly with the type of evaporator and the product being concentrated. Vertical calandria-type evaporators can produce a condensate almost free of entrained milk solids; there appears to be more carry-over with other types of evaporators.

Analysis of the condensate before reuse will show what type of pretreatment is required, if any, for a particular purpose. In regions where the water supply is often hard owing to the dolomitic formations from which it is abstracted, reuse as boiler feed-water is of special interest. Neutralization of acidic condensate and de-aeration followed

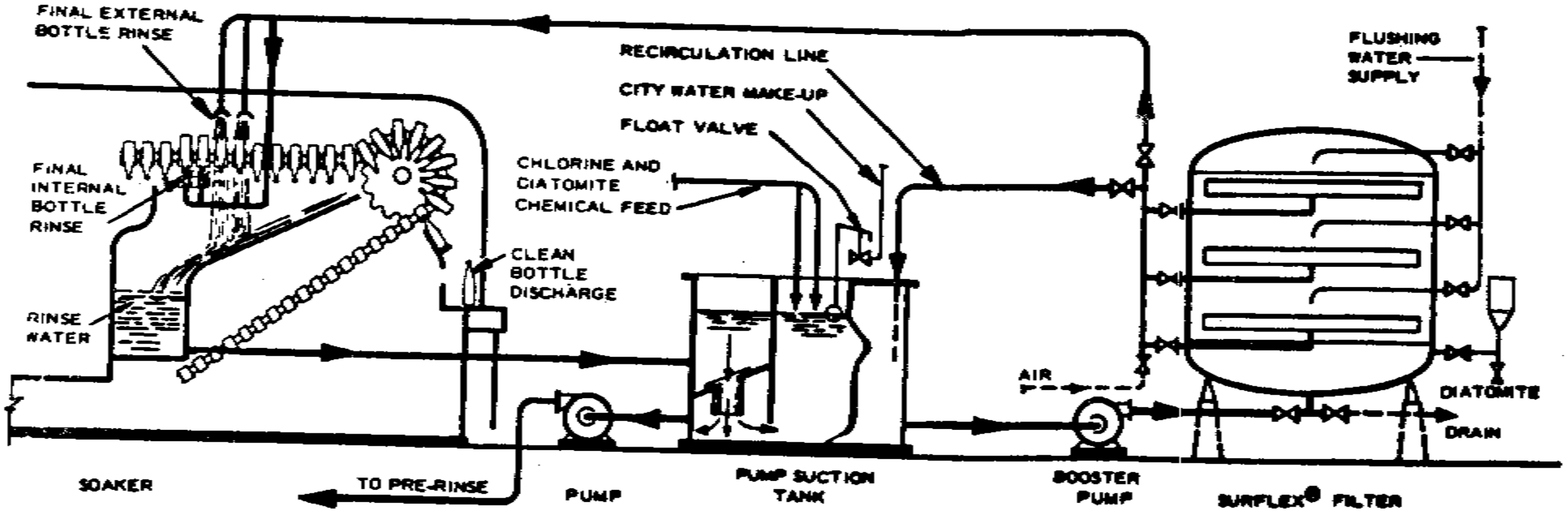

FIGURE 14

Rinse water reclamation in bottle washing. INFILCO – scheme

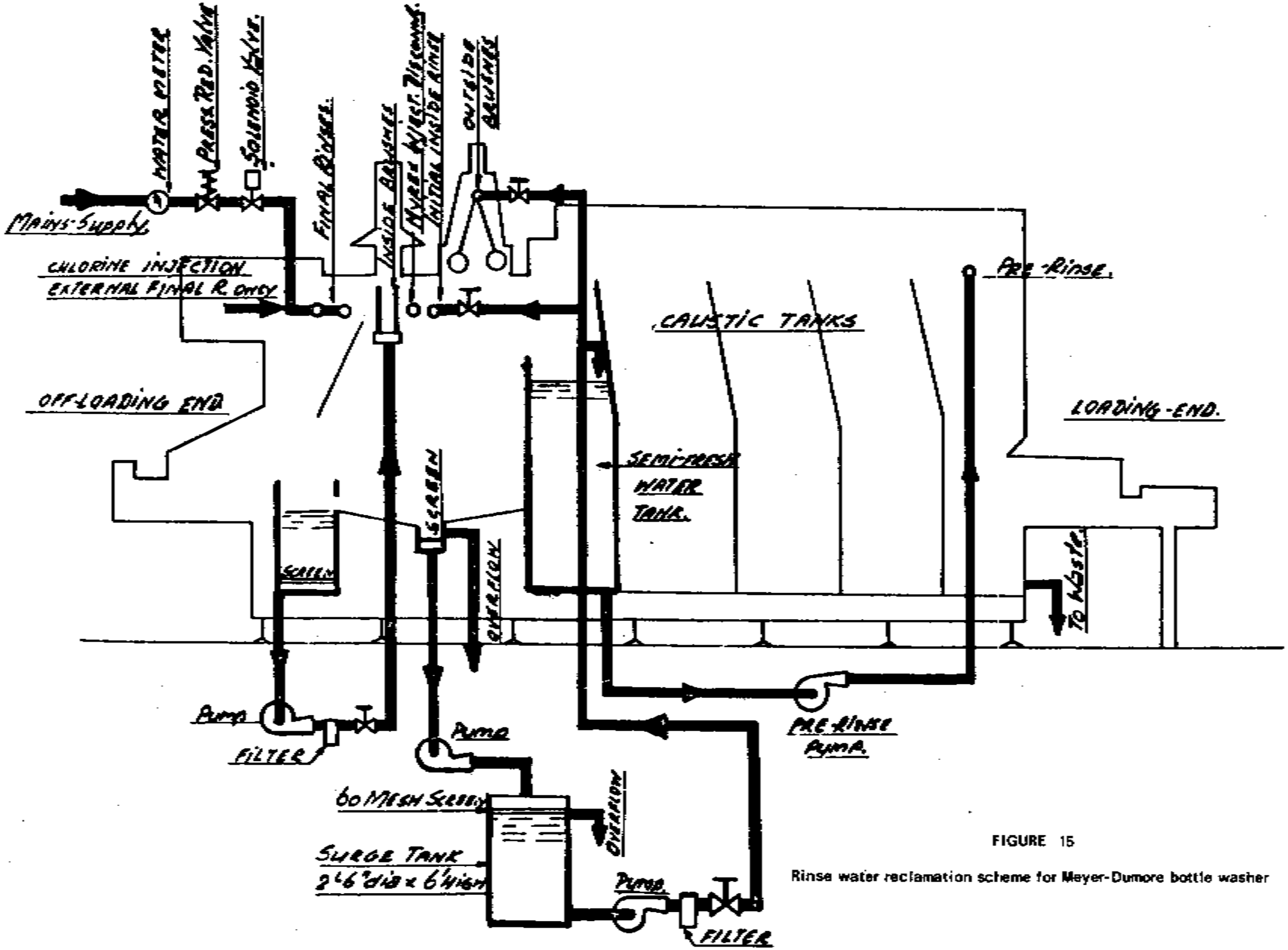

FIGURE 15

Rinse water reclamation scheme for Meyer-Dumore bottle washer

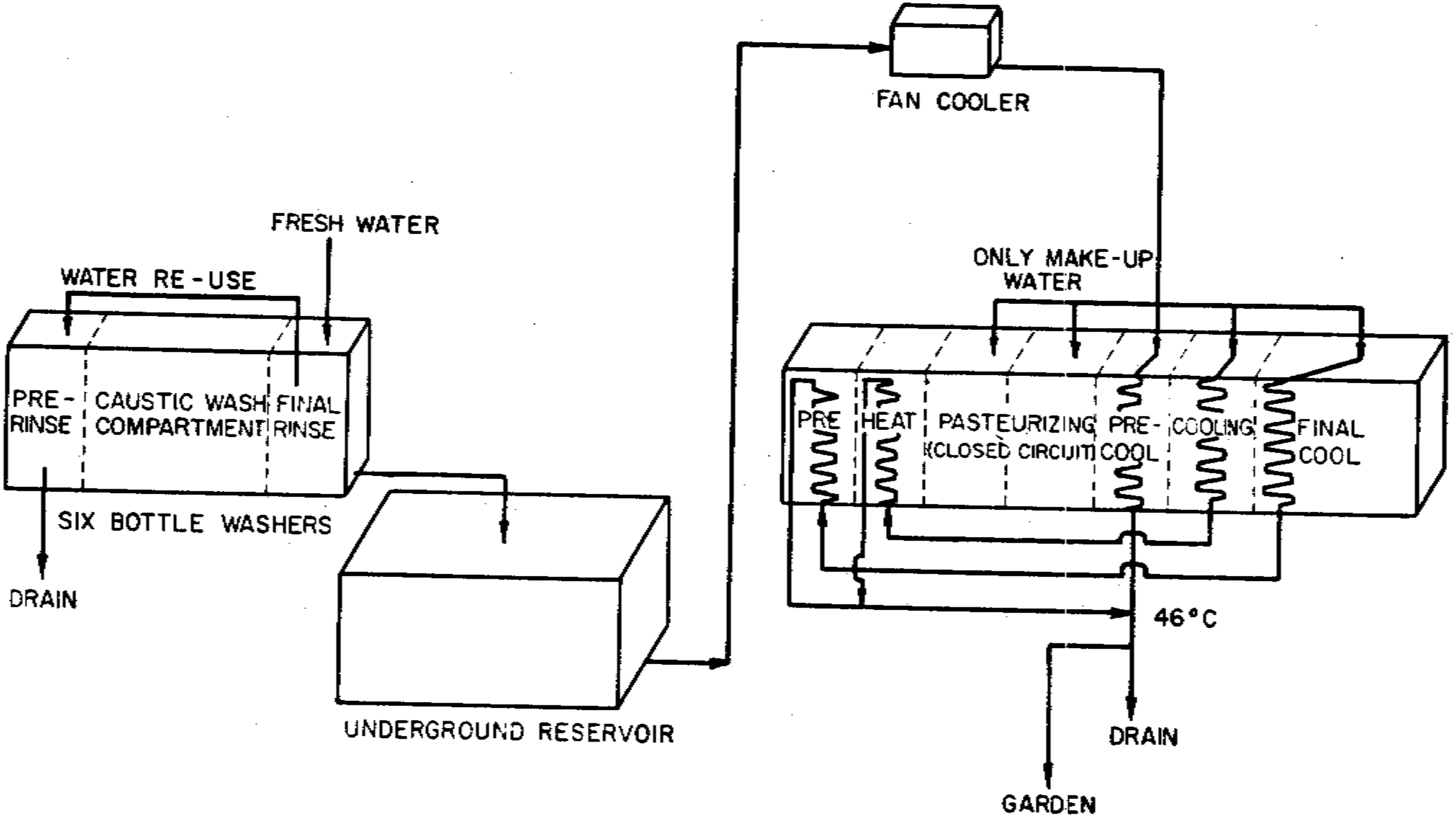

FIGURE 16

Water reclamation scheme at the bottling plant of a brewery by the addition of oxygen scavengers such as Na_2SO_3 or hydrazine may be the only treatment necessary to obtain a sufficiently soft and suitable water supply.

Steam distribution and steam condensate return

Steam distribution lines with too small a diameter cause an excessive drop in pressure and result in an inadequate steam supply. A more or less correct knowledge of the steam requirements for each application is, therefore, essential before installing pipelines and manifolds to ensure that they are of large enough diameter to give an adequate steam supply.

Steam strainers for separating rust and scale particles should be installed in pipes ahead of pressure-reducers or control instruments or valves. Attention to such matters can prevent product deterioration caused by the presence of iron and will also reduce the maintenance costs on instruments.

Excessive amounts of condensate present in the steam reduce the heat-transfer efficiency of e.g. steam-jacketed vessels. Steam lines should, therefore, be as short as possible if large heat losses and the build-up of condensate in reticulation lines are to be prevented. Thermal insulation of steam pipes to minimize heat losses reduces condensation. The withdrawal of condensate from steam lines and steam-heated equipment is important if there is to be optimum heat transfer: this involves the correct location of condensate-traps and drain valves and also the positioning of steam take-offs at the high points of steam lines.

One of the major sources of unnecessary heat and water losses is leaking steam traps. Wherever possible, steam condensate should be recovered and returned to the boiler. Since steam condensate in contact with air rapidly absorbs oxygen it becomes highly corrosive and de-aeration of the condensate by heating, followed by the addition of oxygen scavengers is essential before returning it to the boilers.

Introduction of non-return packages

Small bottle washing machines are not always a guarantee that bottles are effectively cleaned and sterilized as the action time of the sterilants is too short, especially in summer-time, the evidence being that fly larvae are sometimes found in cleaned bottles. Since bottle washers are also one of the largest water users in a milk-bottling plant, the introduction of non-return packages should be seriously considered.

Improvement of plant design

The correct lay-out of the building providing for minimum manual handling of cans in the milk reception, the correct size of the building and equipment, and the incorporation of all the measures listed previously (on pages 20-26) will help to reduce fresh water intake requirements for cooling and cleaning.

Figure 17 shows the well-designed lay-out of a medium-sized pasteurizing and bottling plant.

3. INDUSTRIAL EFFLUENT MANAGEMENT

WATER ACT 1956 AND CITY DRAINAGE BY-LAWS

The acquisition of the right quality raw water for steam raising, cooling and product processing costs money, as does the discharge of effluent. It is the aim of the Water Act of 1956 to protect our limited water resources. In terms of Section 21 of the Water Act 54, specifications have been promulgated to which any effluent resulting from the use of water for industrial purposes must conform, after purification - the so-called General Standards. Any industry disposing its trade waste direct into a public stream, or any municipality discharging its industrial and domestic effluent must conform to the requirements specified in the General Standards except in cases where relaxed standards have been granted by the Department of Water Affairs.

Municipalities have their own acceptance limits for industrial wastes as specified in the Drainage By-laws, which differ from place to place.

Table 9 refers to the effluent standards imposed by the Water Act (General Standards) and the trade-waste acceptance limits of Johannesburg, Pretoria and Durban city councils.

Industries served by municipal sewage systems are much better off, as can be seen from the more lenient limits of acceptance, shown in Table 9. In this latter case the municipalities with their extensive treatment facilities accept the responsibility for discharging a purified effluent into the public watercourse, and for ensuring that it conforms to the General Standards of the Water Act. As municipal effluents contain a large percentage of domestic, easily biodegradable matter, they are naturally able to tolerate the addition of concentrated or polluted trade wastes.

TREATMENT COSTS

Treatment costs for effluents are directly related to the flow and organic loadings of the effluents. Although the acceptance and treatment tariffs usually vary from place to place, the annual costs for treatment could be considerably diminished by reductions both in flows and organic loadings.

The strength and volume of dairy effluents will obviously be much influenced by the amount of milk that goes to waste. For this reason and also to diminish direct financial loss, every effort should be made to reduce milk wastage.

Treatment charges levied by local authorities are usually based on:

(a) pumping costs (volume); and

(b) organic pollution of the effluent, expressed as mg/l OA (oxygen absorbed by N/80 $KMnO_4$ at 27°C).

The effluent treatment charges can, therefore, be reduced in two ways: firstly by reducing the intake-water requirement and secondly by reducing the wastage of milk or milk products.

TABLE 9

SPECIFICATION FOR EFFLUENTS

(Maximum permissible concentrations)

[All units in mg/l except otherwise stated]

	Water Act No. 54, 1956	City drainage by-laws		
	General Standards (15)	Johannesburg	Pretoria	Durban
pH	5.5 - 9.5	> 6.0	6 - 10	> 6.0
Faecal coli	Nil	N.S	N.S	N.S
Dissolved O_2	> 75%	N.S	N.S	N.S
Temperature	35°C	N.S	N.S	< 100°F
Chemical oxygen demand (COD)	75	N.S	5,000	N.S
4 hrs OA	10	1,400	200	N.S
TDS	Not increasing to more than 500 above intake	N.S	2,000	N.S
Electrical conductivity	N.S	5,000 micromhos	N.S	N.S
Suspended solids	max. 25	N.S	600	2,000
Sodium (as Na)	90 Not more than 50 above intake	N.S	75	N.S
Soap, oil and grease	max. 2.5	N.S	400	50
Substances not in solution (incl. fat, oil, grease, waxes, etc.)	N.S	2,000	N.S	N.S
Substances soluble in petroleum ether	N.S	500	N.S	N.S
Chlorides	N.S	N.S	N.S	1,000
Free Cl	max. 0.1	100	N.S	N.S
Free and saline NH_3	10	N.S	N.S	N.S
Phosphates (as P)	N.S	N.S	Nil	N.S
Silver (as Ag)	N.S	N.S	Nil	N.S
Iron (as Fe)	N.S	total concentration of all metals 50; individual metal 20	N.S	N.S
Chromium (as Cr)	0.5		20	50
Copper (as Cu)	1.0		20	50
Nickel (as Ni)	N.S		20	50
Zinc (as Zu)	5.0		20	50
Cadmium (as Cd)	N.S		20	50
Arsenic (as As)	0.5	total of all metals 20; individual metal 5	N.S	N.S
Boron (as B)	1.0		N.S	N.S
Lead (as Pb)	1.0		N.S	N.S
Selenium (as Se)	N.S		N.S	N.S
Mercury (as Hg)	N.S		N.S	N.S
Sulphides (as S)	1.0	50	20	50
Fluorides (as F)	1.0	5	N.S	N.S
Phenols	0.1	N.S	N.S	N.S
Formaldehyde	N.S	50	N.S	N.S
Cyanides (as CN)	0.5	20	10	20
Total sugars and starch	N.S	1,500	N.S	1,500
Tar and tar oils not soluble in water	N.S	N.S	60	60
Calcium carbide	N.S	Nil	Nil	Nil
Total sulphates	N.S	1,800	300	200*

N.S = Not specified   * sulphate in solution

The most important limits for the milk-processing industry from this long list are the specifications for: chemical oxygen demand; OA; Na^+; soap, oil and grease; free and saline NH_3

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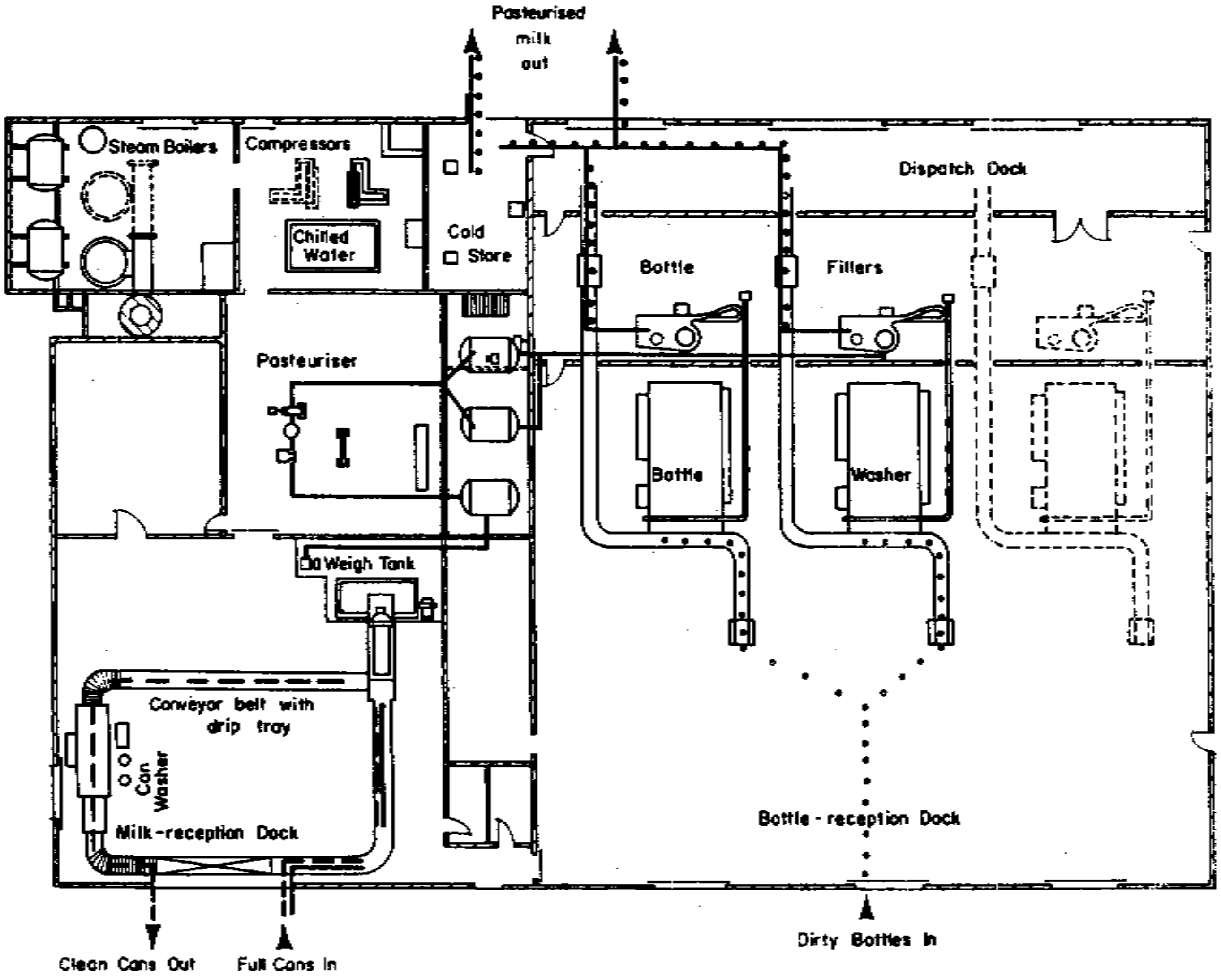

FIGURE 17

Lay-out for a medium-sized pasteurising and bottling dairy

Reduction of the effluent volume can be achieved by -

(i) the introduction of water-saving measures such as fitting every water hose or tap with an automatic shut-off valve or by those listed on pages 22 - 24.

(ii) the separation of 'clean' effluent streams, e.g. refrigerant cooling water, jacket water for cooling vacuum pumps or refrigerant compressors, steam condensate etc., for reuse as cooling water, boiler feed or as equipment and floor wash-water.

POLLUTION CHARACTERISTICS OF MILK WASTES

Milk wastes contain fats, proteins and carbohydrates in various dilutions; in addition, some spent detergents discharged from washing operations. To combat fly nuisance, DDT-containing or other bio-resistant insecticides are sprayed generously and these may find their way into the effluent. Such insecticides can interfere with the efficiency of biological treatment units. Milk bottle caps, wire from securing lids, cartons, matches, etc. are solids also found in the effluent.

Milk products mixed with water exhibit a marked de-oxygenating effect. The oxygen in the water is consumed very rapidly as a result of biological oxidation, and when it becomes depleted, anaerobic conditions result, followed by putrefaction and the development of objectionable odours. This decomposition is accompanied by separation of a certain amount of fat, acid formation of sugars and coagulation and proteolysis of the casein.

Table 10 reflects the average oxygen absorption (4 hrs OA) or permanganate value (PV), and chemical and biological oxygen demand (COD and 5 days BOD), of the most important liquid milk products in the milk waste, and their polluting strength in terms of population equivalent (PE).

TABLE 10

4 HRS OA, COD AND BOD OF MILK PRODUCTS AND THEIR POLLUTING STRENGTH IN TERMS OF POPULATION EQUIVALENTS (PE)

(mg/l)

Product	4 hrs OA	COD	BOD	PE/litre product	PE/gal product
Whole milk	9,000	190,000	121,000	2.2	10.2
Skim milk	8,250	102,000	75,000	1.4	6.3
Buttermilk	8,250	102,000	73,000	1.4	6.1
First butter rinse	460	7,300	6,800	0.1	0.6
Whey	5,900	69,000	42,000	0.8	3.5

Figures for population equivalents are based on BOD_5
1 PE = 54 g BOD/person/day

If dairy wastes equal to 45 litres (10 gallons) of whole milk were dumped into a lake, the resulting bacterial action on this amount of food would require all the oxygen dissolved in approximately 900 m^3 (200,000 gallons) of saturated lake water for complete oxidation of the milk-solids. Until the bacterial demands for oxygen were satisfied, no oxygen would be available in this part of the lake for fish or plant life. It is the tremendous polluting effect of this hugh oxygen-demanding waste that makes prior treatment of it necessary before it is drained into a natural watercourse.

Milk is not only a well-composed food, it is also an excellent breeding medium for many bacteria. Therefore, the discharge of milk-containing effluents into public streams etc. or their disposal by irrigating or spraying in the vicinity of a borehole may constitute a hazard, especially in dolomitic or shale rock strata where pollution of the borehole may occur through cracks by channelling.

SOURCES OF WASTAGE

Unless the milk losses are sufficiently high to affect that economy of plant operations, nothing is done about them until the particular dairy is confronted with high costs for treating its effluent. Milk losses of 2 - 3 per cent of the quantity of the milk handled and more, seem to be tolerated in many milk-processing plants, although accidental milk losses as a result of can-handling, breakage of bottles or from other sources can be kept as low as ½ to 1 per cent in well-managed dairy plants.

Perhaps the largest volume of milk-solids entering the municipal drains is disposed of wilfully because of indifference to the recovery of by-products. Although larger milk-processing factories try to recover and utilize by-products, there are still many smaller plants which, by discharging surplus butter-milk, skim-milk or whey, are responsible for large volumes of strongly polluted effluent. The disposal of these products of high nutritional value requires urgent investigation because of the increase they cause in the pollution load that has to be handled at effluent-treatment works.

An increase in the milk-drying capacity of milk condenseries so that they are able to cope with the surplus 'summer flush' of milk and the provision of additional transport to milk-drying plants during the summer, offer a possible solution to this problem.

BY-PRODUCTS RECOVERY

The principal methods of utilizing skim-milk, butter-milk and whey are:

(1) maximum concentration by conversion into dried products to be used either for human food or animal food products; the dried products have the advantage that they can, under suitable conditions, be stored for many months without harm to their physical or nutritional properties;

(2) conversion into other products, e.g. skim-milk into casein, butter-milk into thickened butter-milk, whey into yeast.

(3) direct feeding to livestock.

The nutritional value of whey for pig feeding is quite high: one gallon of whey is the equivalent in nutrient value of 0.3 kg (0.7 lbs) grain. Daily feed doses of 14 - 18 litre (3 - 4 gal) per pig and 45 - 55 litre (10 - 12 gal) per head of cattle are possible(16).

According to overseas literature, the utilization of surplus whey for the production of yeast, lactose and other products is probably an even more rewarding outlet for whey than flushing it through the drain or using it for irrigation (17,18).

Of all the milk constituents butterfat fetches the highest price. Therefore, its complete separation from the effluent will be a paying proposition. Dry milk and milk-containing rinse waters from the various cleaning operations should be run through a separator which salvages the butterfat. One American milk-processing plant which collects all the rinse waters in a tank for processing in a separator has published the following recovery figures(19):

	Rinse water lb	Butter-fat %	Recoverable fat lb
Storage tank 3,000 gal	120	1.20	1.4
Storage tank 6,000 gal	170	2.30	3.9
Homogenizer	62	2.05	1.3
Cooler and connecting pipe	100	1.20	1.2
Product lines	68	2.20	1.5
Cream vat 600 gal	80	2.75	2.2

N.B. 220 gal = 1 m^3; 2.2 lb = 1 kg

There are, in addition, smaller items of equipment. As some of the items are duplicated and some of the tanks are used more than once a day, it was calculated that the maximum possible recovery was 23 kg (50 lbs) of fat per day; the actual recovery was 18 kg (40 lbs) per day, which amounted to 544 kg (1,200 lbs) per month or 6,500 kg (14,400 lbs) per year, representing a considerable amount of money.

Table 11 reflects the average analysis data of the most important milk products obtained under South African conditions.

TABLE 11

AVERAGE ANALYSIS DATA OF MILK AND MILK BY-PRODUCTS OBTAINED UNDER SOUTH AFRICAN CONDITIONS

(Percentage w/w)

	Proteins	Fat	Lactose	Total solids
Whole milk	3.0	3.6	4.8	11.4
Skim-milk	3.1	0.05	5.0	8.1
Butter-milk	3.4	0.8	3.8	8.0
Whey	0.7	0.05	5.3	6.0

PROPOSED METHODS FOR EFFLUENT TREATMENT

Flow measurement

Before planning a treatment plant for dairy wastes it is essential to know the volume to be treated daily. The simplest method of finding this out is to insert a sharp-crested 45° or 90° V-notch into an open channel down which the effluent flows; for larger waste flows a rectangular weir is inserted into an open channel, or even better, into a stilling box provided with a stilling baffle plate to eliminate turbulence.

The 25 cm (10 inch) V-notch is a simple and precise device for measuring small discharges of the order of 0.05 to 2.7 m^3 (10 to 600 gal) per minute. The plates have to be cut out to form either a 90° notch or a 45° notch. The angle is selected to provide a head over the notch which does not exceed 25 cm (10 inch). This limit is set by the range of the pressure recorder, an instrument used for obtaining a permanent reading of the daily flow pattern; for accurate measurement the flow should not fall below 5 cm (2 inch).

For measuring flows in excess of about 1 m^3 (220 gal) per minute, rectangular-shaped weirs with sharp edges provide a convenient method of measurement. For a weir with a maximum head of 25 cm (10 inch) the maximum colume which could be metered is about 10 m^3 or exactly 2,260 gal per minute for 76 cm (30 inch) width, and 3 m^3 (640 gal) per minute for 23 cm (9 inch) width.

For accurate flow measurement with these metering devices, the V-notch and the weir have to be inserted exactly level into the open channel so that they are tight-fit, since no seepage must occur at the bottom or the sides of the installed flow-restricting metering equipment.

The weir must be kept clean. No sediment should be allowed to accumulate at the back of the weir since this will lead to erroneous flow readings.

The point where, for accurate reading, the calibrated gauge is to be permanently fixed should be upstream at a distance from the weir of 2 to 4 times the height of the weir, provided that the channel is level.

Spot flow readings can be obtained by watching a calibrated gauge. To obtain the pattern of the daily flow, and to record the minimum and peak flows, a pressure recorder should be used, connected by means of a T-piece and a suitable length of rubber tubing to a continuous air-supply and to a 3/8 inch copper stand pipe in the channel or stilling box. This stand pipe should be installed at a distance of 2 to 4 times the height of the weir. Where the location or shape or fall of the channel does not permit this installation, the 3/8 inch stand pipe can be solidly clamped on at the upstream side of the restriction plate. The lower end of this pipe should then be extended about 1 cm (½ inch) below the edge of the V or the cut-out rectangular opening to compensate for the reduced height of the wave above the weir plate. The air supply is conveniently provided by a steel bottle of compressed air. The supply must be regulated so that only about two air bubbles per second escape through the stand pipe into the liquid. A smaller air supply can hardly be controlled; on the other hand with a larger air supply an unduly high pressure may develop in the instrument and this may result in readings that are too high, or may even damage the bellows inside the instrument.

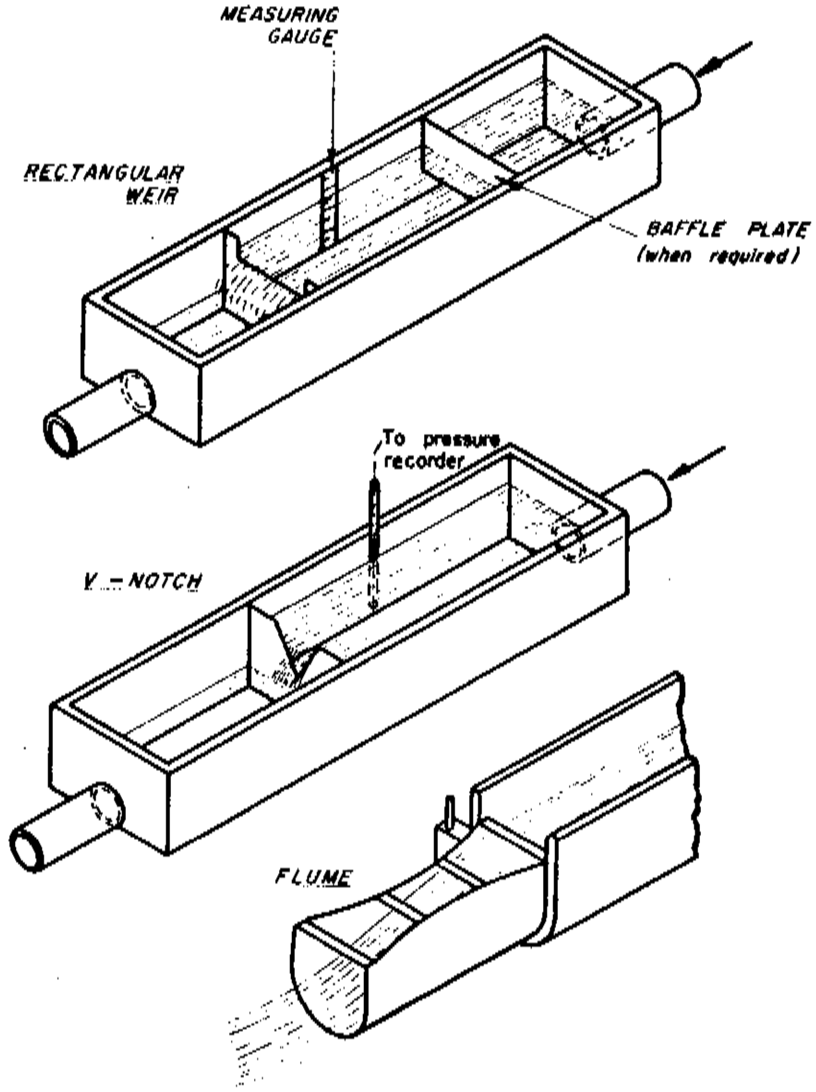

FIGURE 18

Simple flow measuring installations

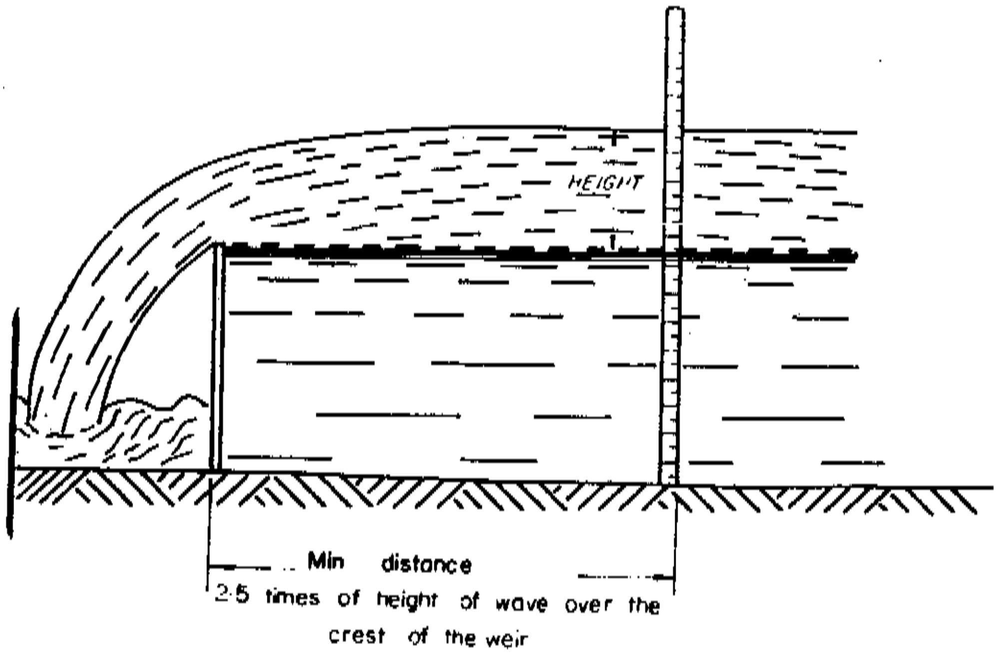

FIGURE 19

Ideal set-up for measuring the height of flow over a weir

Figures 18, 19 and 20 illustrate the layout of simple flow-measuring equipment which can easily be installed in open channels, either as temporary or as permanent equipment. For permanent measuring of large flows where floating solids may interfere with the measuring equipment, a standing wave-measuring flume with a local recorder should be used as shown in Figure 21.

Tables 12 and 13 indicate the flow in gallons/15 minutes for a 90° V-notch and a 23 cm (9 inch) rectangular weir. These tables supply answers accurate to within 10 per cent if reasonable care is exercised in its installation and in taking readings; this is accurate enough for most waste problems.

Segregation of drain systems

There is no reason why cooling water, boiler blow-down, spent bottle wash water, or other 'clean' effluents free from milk solids, should run to waste and be treated in effluent treatment plants. Since volume is the greatest cost factor in effluent treatment the wastage of these 'clean' effluents constitutes an unnecessary cost factor.

Provision of a separate drain system and an adequate collecting tank to store clean effluents for reuse as cooling water or for plant and equipment washing reduces the costs for effluent treatment because it reduces the volume of effluent to be handled.

The sulphuric acid used in butterfat testing should not be dumped into the sewer as it may attack concrete; instead it should be dumped separately onto the boiler ash heap or, where an oil-fired or electric boiler is used, poured into a hole containing agricultural lime (calcium carbonate).

Screening

To prevent blockage of sewer pipes with broken bottles, bottle caps, wire, wrapping paper or other solid matter, it is advisable to fit screens made of 1 cm (½ inch) weir mesh into drain channels.

Balancing

Extreme fluctuations in flow, composition or strength of effluents adversely affect any form of treatment.

Dairy plant effluents, because of the plant-operating schedule, are produced during a relatively short period of the day with peak volumes and pollution loads during milk reception, and the clean-up operations a few hours later. Since effluent treatment charges in most towns in South Africa are normally based on the average OA concentration of one grab sample per month which is usually taken during morning hours to give the town's biochemist time to complete the analysis before 5 pm, it is quite likely that treatment charges are based on samples taken during peak discharge times. This practice could lead to the overdesign of the sewage purification works and a possible inadvertent overcharge for the treatment of effluents. It is, therefore, in the interest of both the factory and the sewage purification authority to ensure that balancing facilities are installed to regularize the fluctuations in flow and pollution load.

TABLE 12

FLOW MEASUREMENTS USING A 90° V-NOTCH. (DISCHARGE IN GAL/15 MIN. FOR EVERY TENTH OF AN INCH)

inches	gal/15 min	inches	gal/15 min	inches	gal/15 min
0.1	0.15	3.4	630	6.7	3360
0.2	0.90	3.5	680	6.8	3500
0.3	1.65	3.6	720	6.9	3610
0.4	3.05	3.7	770	7.0	3730
0.5	5.55	3.8	830	7.1	3850
0.6	8.70	3.9	880	7.2	4000
0.7	12.7	4.0	940	7.3	4150
0.8	17.7	4.1	1000	7.4	4300
0.9	23.5	4.2	1060	7.5	4450
1.0	30.5	4.3	1120	7.6	4600
1.1	38.7	4.4	1190	7.7	4750
1.2	48.0	4.5	1250	7.8	4900
1.3	59.0	4.6	1320	7.9	5050
1.4	70.0	4.7	1400	8.0	5200
1.5	85.0	4.8	1470	8.1	5350
1.6	100	4.9	1540	8.2	5500
1.7	115	5.0	1630	8.3	5670
1.8	130	5.1	1720	8.4	5820
1.9	150	5.2	1800	8.5	6000
2.0	170	5.3	1880	8.6	6190
2.1	190	5.4	1970	8.7	6380
2.2	210	5.5	2060	8.8	6580
2.3	240	5.6	2160	8.9	6780
2.4	270	5.7	2260	9.0	6980
2.5	300	5.8	2360	9.1	7180
2.6	330	5.9	2460	9.2	7380
2.7	360	6.0	2560	9.3	7580
2.8	390	6.1	2670	9.4	7780
2.9	425	6.2	2780	9.5	7980
3.0	460	6.3	2890	9.6	8180
3.1	500	6.4	3000	9.7	8380
3.2	540	6.5	3140	9.8	8580
3.3	580	6.6	3260	9.9	8850
				10.0	9200

<u>Note:</u> 1 gallon = 4.546 litre
220 gallons = 1 m^3

TABLE 13

FLOW MEASUREMENTS USING A FULLY CONTRACTED RECTANGULAR WEIR, WIDTH 23 cm (9 INCHES). (DISCHARGE IN GAL/15 MIN. FOR EVERY TENTH OF AN INCH)

Inches	gal/15 min	inches	gal/15 min	inches	gal/15 min
0.1	10.77	3.4	2057	6.7	5474
0.2	30.39	3.5	2146	6.8	5587
0.3	55.87	3.6	2236	6.9	5705
0.4	85.87	3.7	2327	7.0	5822
0.5	119.9	3.8	2419	7.1	5940
0.6	157.4	3.9	2512	7.2	6061
0.7	198.1	4.0	2607	7.3	6178
0.8	241.8	4.1	2702	7.4	6299
0.9	288.1	4.2	2797	7.5	6421
1.0	337.1	4.3	2896	7.6	6538
1.1	388.3	4.4	2994	7.7	6663
1.2	442.1	4.5	3102	7.8	6784
1.3	498.1	4.6	3192	7.9	6906
1.4	556.1	4.7	3293	8.0	7031
1.5	616.3	4.8	3395	8.1	7152
1.6	677.7	4.9	3497	8.2	7277
1.7	741.3	5.0	3600	8.3	7402
1.8	806.8	5.1	3706	8.4	7527
1.9	873.9	5.2	3811	8.5	7652
2.0	942.8	5.3	3913	8.6	7781
2.1	1013	5.4	4023	8.7	7902
2.2	1085	5.5	4129	8.8	8031
2.3	1159	5.6	4235	8.9	8159
2.4	1234	5.7	4345	9.0	8284
2.5	1310	5.8	4451	9.1	8413
2.6	1388	5.9	4565	9.2	8538
2.7	1467	6.0	4678	9.3	8671
2.8	1548	6.1	4788	9.4	8803
2.9	1630	6.2	4902	9.5	8928
3.0	1713	6.3	5012	9.6	9061
3.1	1797	6.4	5125	9.7	9190
3.2	1882	6.5	5243	9.8	9322
3.3	1969	6.6	5356	9.9	9451
				10.0	9584

Note: 1 gallon = 4.546 litre
220 gallons = 1 m^3

Technical Guide K12, Pretoria, CSIR, 1970

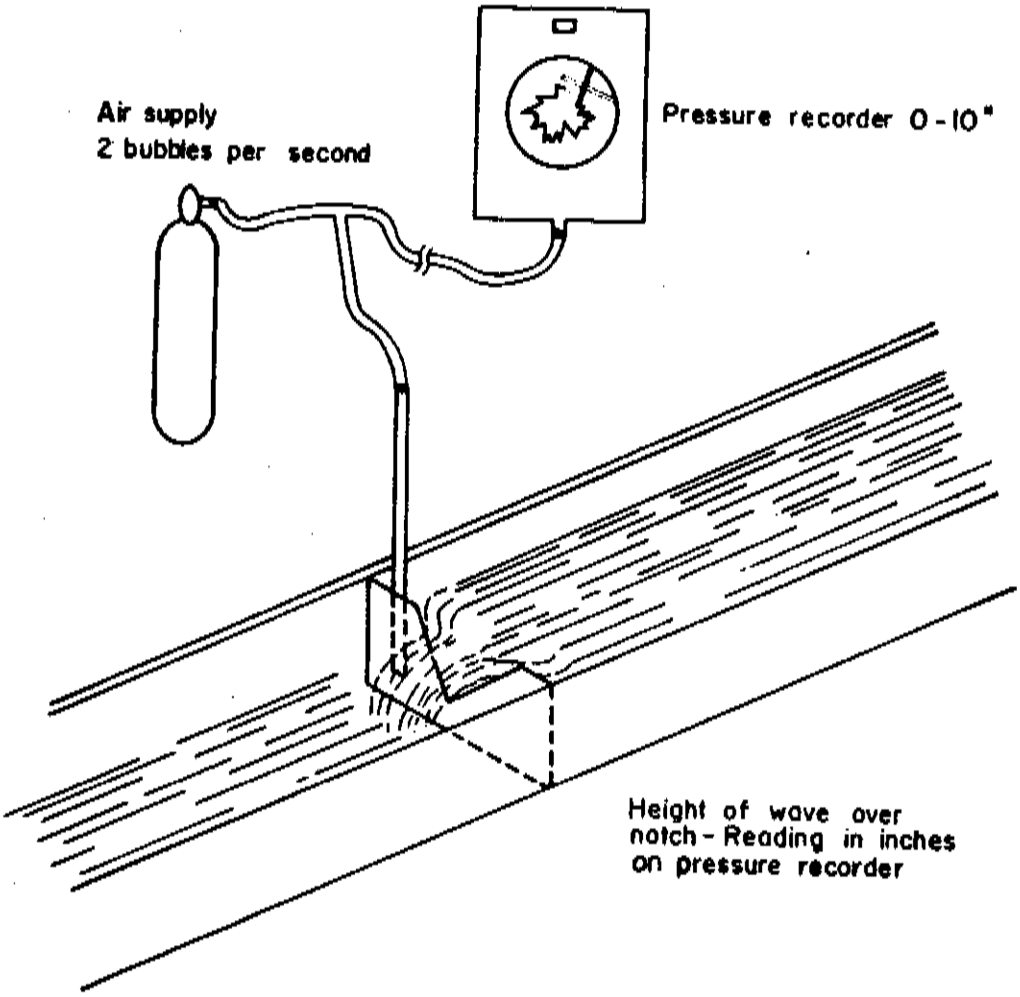

FIGURE 20

Set-up of flow measuring equipment

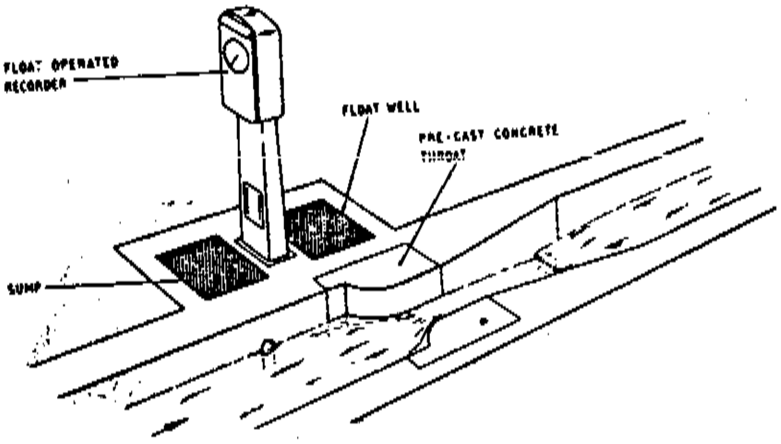

FIGURE 21

Standing wave measuring flume with local recorder

Separation of fat

In the case of effluents containing fatty milk-solids, the separation of these by means of a separator or fat trap prior to disposal is essential. Fat in the effluent will clog sewer pipes, especially if other solid matter such as wire from can lids, milk caps, paper or pieces of carton are flushed down the drain at the same time. Costly sewage-treatment units such as biofilters may also become choked with fat. Of the various constituents in milk, fat is the most difficult to break down by bio-oxidation treatment. If used for irrigation, fat-containing effluents tend to clog the soil, thereby rendering the area unsuitable for further irrigation.

Fat traps are buffer tanks with baffle plates which allow the lighter fat globules to float to the surface. This separated layer of fat has to be skimmed off daily; since fat prevents the access of air, anaerobic conditions may set in accompanied by smell and fly nuisance. Aeration of fat traps by means of a diffuser jet at the bottom of the fat trap improves the rate of separation and simultaneously keeps the effluent fresh.

For good separation of the fat, the surface area of a fat trap should be 0.4 m^2/m^3 (20 ft^2/1000 gal) of maximum hourly flow. The tank should be about twice to three times as long as it is wide; and its width should be at least 76 cm (30 inches) to facilitate the easy removal of grit from the bottom of the tank. A perforated metal screen with 9 mm (3/8 inch) perforations should be placed at an angle of 60° to the horizontal for straining out the solids. For the removal of grit the tank should provide about 10 minutes retention time at maximum flow. Consequently, a tank 2½ ft x 2½ ft x 8 ft would in most cases by adequate for removing grit and fat for a flow of 1000 gallons per hour(20).

Fat traps should be neither too small nor too large. When a fat trap is too small too little of the fat separates out, while the contents of too large a trap with too long a retention period will turn sour. Once the fermentation of milk-sugars has caused the pH level to drop sufficiently, the proteins will be precipitated and adsorbed onto the fat globules which will rise to the surface and form a seal which will prevent the access of air thus causing anaerobic conditions.

Liming the effluents in excessively large fat traps is one way of preventing the wastes from turning sour and creating anaerobic conditions and smell nuisance.

When operating a large fat trap with a small waste flow, as may be the case during off-season periods, another method of preventing anaerobic conditions is to keep the wastes at a predetermined low-level range, e.g. between 2 ft and 3 ft by means of a float-controlled centrifugal pump. This method shortens the retention time and the danger of an effluent turning sour and consequently becoming anaerobic and smelly is reduced.

Encaging the fat traps with fly-screens to prevent excessive breeding of flies reduces the need for spraying insecticides.

A minimum detention period of 30 minutes is recommended for the efficient separation of fat.

Fat traps should be located as near as possible to the source of the fat-containing effluents.

The best method of disposing of the fat separated from fat traps, and the sludge from cream separation is by burning them under the boiler; burying them in the field is another method widely practised.

Figure 22 shows the layout of a simple fat trap.

Treatment processes

The treatment of milk wastes by chemical precipitation reduces the pollution load to a certain extent, but it does not eliminate the need for additional biological treatment. The use of either iron or aluminium salts to precipitate the protein in the waste has been found unsatisfactory because:

(1) the lactose is not affected and remains in solution.

(2) there is such a large volume of sludge that it creates a disposal problem.

Milk wastes are exceptionally easy to treat by aerobic fermentation processes, since milk is an ideal substrate for aerobic organisms. The lactose is quickly converted to simpler products, namely H_2O and CO_2; the proteins are split and digested by the microorganisms, while milk fat in small quantities offers no problem. Three aerobic treatment processes have proved successful in practice:

(1) the biofilter (two-stage alternating biofiltration);

(2) the activated sludge process (tank aeration); and

(3) the extended aeration process, employing the oxidation ditch.

Extensive investigation on the bio-oxidation of dairy wastes has established the amount of oxygen required and the rate at which oxygen must be supplied to treat dairy wastes successfully. Each kg of organic matter in dairy wastes, as contained in 10 litres of whole milk, requires about 1.2 kg of oxygen for complete oxidation (1 lb organic matter in 1 gal milk requires 1.2 lb oxygen). This oxygen requirement is more or less equivalent to the 'chemical oxygen demand' (COD) which can be determined by the rapid method described in Appendix 1.

(1) Biofilter

The biofilter consists of a bed of stones over which the wastes to be treated are sprayed. This practice simulates the purification process of a stream flowing over a rocky bed. The stones provide a base for microorganisms which in the presence of air circulating through the filter bed, attack the organic matter of the effluent and use it for food. As these organisms multiply, they break away from the stones and must, therefore, be removed from the water in a settling tank following the biofilter. The resulting effluent is usually clean and can be discharged with or without further pond treatment into the receiving stream.

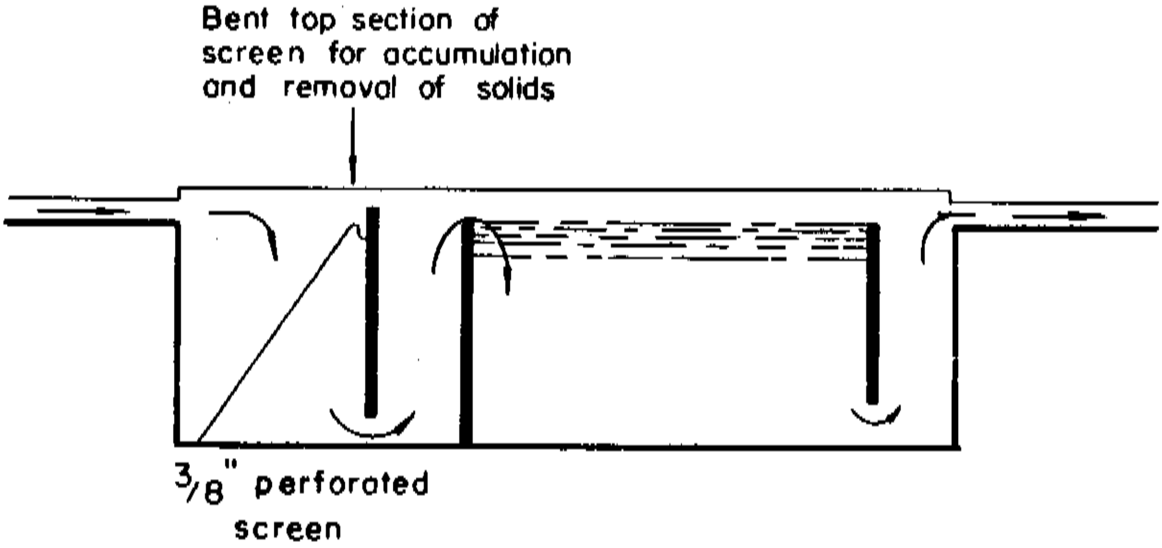

FIGURE 22

Fat-trap for dairy wastes

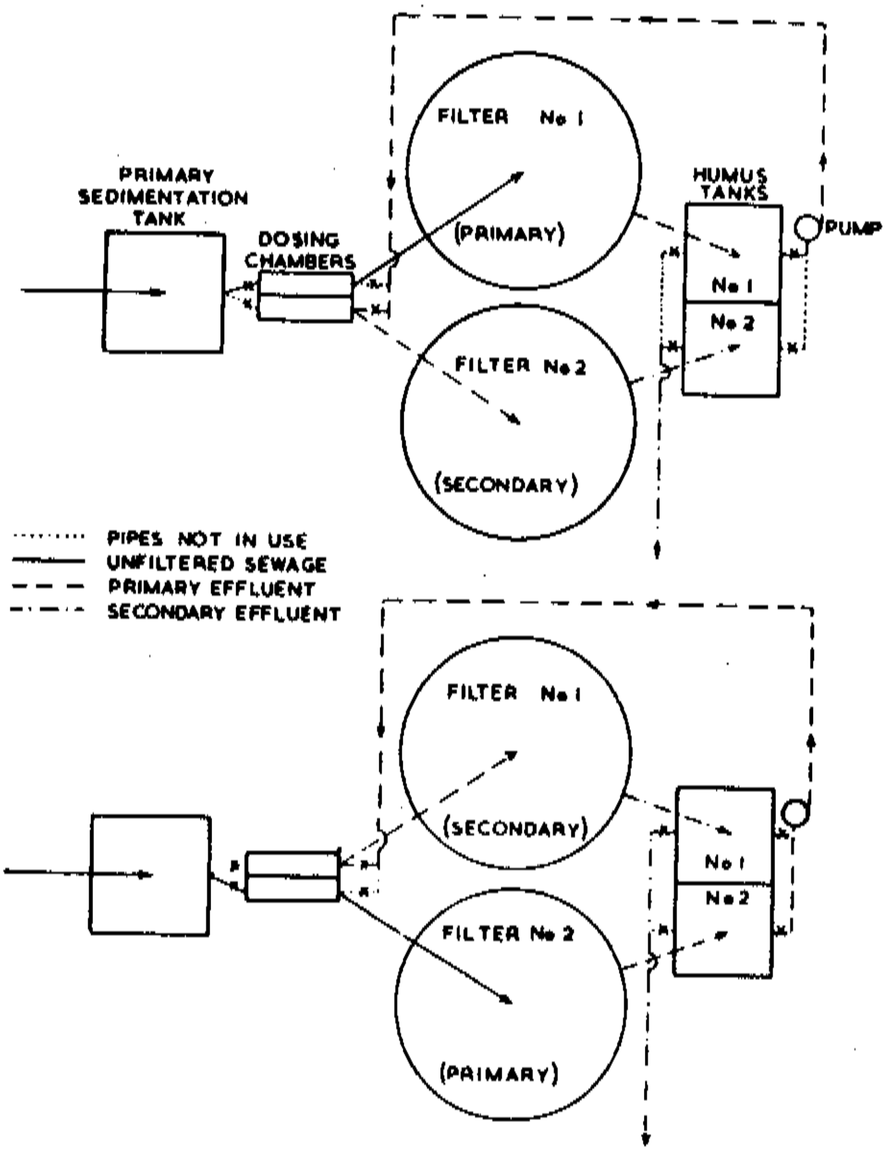

FIGURE 23

Diagram showing arrangement for the treatment of settled sewage by alternating double filtration

The sludge that accumulates in the settling tank consists mostly of organic matter which requires further treatment to prevent fly nuisance and to render it suitable for disposal. Digestion under anaerobic conditions in a digester produces methane and carbon dioxide and a mineralized residue which, after drying on drying beds, can be utilized as low grade fertilizer. When the volumes of sludge produced are not large enough to warrant anaerobic digestion, sludge drying may be employed as the only form of treatment. Precautions must then be taken against fly nuisance by locating the drying beds sufficiently far away from the dairy plant.

The once-through flow on biofilters is no longer used for the treatment of milk wastes, but has been replaced by continuous recirculation which practice ensures greater load capacity and is more efficient. The biofilter may be single-stage or two-stage depending upon the degree of purification required. Where alternating double filtration is employed screened and settled milk waste is passed onto a standard biological filter and the effluent, after sedimentation, is then pumped onto a second biological filter and settled.

Two-stage biofiltration units include a primary settling tank, primary and secondary filters, a final settling tank and a sludge digester. Treatment plants of this type can be constructed of concrete or can be delivered as ready-made compact units.

Figure 23 shows the arrangement used for alternating double-filtration employing biofilters.

To produce a good final effluent the biofilters must not be overloaded with organic matter; for alternating two-stage biofilters the permissible load in the filter medium must not be more than 0.3 kg BOD/m^3 (0.5 lb BOD/yd^3) if an effluent with about 10 mg/l BOD is to be produced. The sequence of the two filters is changed at intervals varying from 1 to 7 days, the secondary filter then becoming the primary unit and vice versa. Under these conditions the biological film which forms in the primary filter is loosened and washed out when this filter becomes the secondary unit, and this occurs with each alternation. This limits the overall growth of this film and for this reason the double filtration system can cope with a heavier loading than single-stage biofilters.

(2) Activated sludge treatment

The activated sludge process provides no fixed medium for anchoring the microorganisms comparable to the stones of the biofilter. Instead the microorganisms are suspended in the effluent, being kept in suspension by compressed air or air introduced by mechanical mixing. The air supplies the oxygen necessary for biological activity. The process is kept in operation by withdrawing and settling the treated effluent and recycling a portion of the settled biologically active sludge to mix with the inflowing waste. The sludge is treated in the same way as the biofilter sludge.

Oxidation proceeds in two phases: during the first or assimilation phase the sludge bacteria rapidly consume the food in the milk waste and require oxygen at a high rate; during the second or endogenous phase, because there is no fresh food supply available, the bacteria digest themselves and use considerably less oxygen.

The advantage of tank aeration over biofilter aeration is that it is easier and simpler to install. An aeration tank requires less space than a biofilter and can be located near dairy plants or residences as it does not give rise to objectionable odours. The disadvantage are that it requires more power per pound of organic load removed, and that difficulties may occur because of excessive foaming, and the bulking of sludge.

Experimental studies have shown that to ensure efficient aeration using diffused air requires an air-pressure of 0.21 - 0.70 kg/cm^2 (3 - 10 lb/in^2)at depths of 2 - 4 m (6 - 12 ft) below the surface. As aeration devices incorporating drilled headers with holes of 3 mm (1/8 inch) diameter or less clog quickly, holes of 5 mm (3/16 inch) are recommended. Air ejectors produce small air bubbles with a large surface areas. The rate of oxygen transfer with diffused air systems is of the order of 1 - 2 kg (2.5 - 4 lb)(21).

Mechanical aeration by surface aerators generally requires less power to transfer the oxygen. Transfer rates 2.3 - 3.6 kg (5 - 8 lbs) O_2/kWh are possible at 21°C (70°F).

Figure 24 shows the layout of a continuous-process compact aeration treatment plant for dairy wastes with sludge return to the first aeration compartment. In order to overcome the adverse effects of temperature variations it is advisable to have aeration tanks installed below ground. To maintain a constant temperature during cold winter nights the admixture of hot boiler blow-down is recommended. For maximum efficiency the temperature should be kept between 18 and 32°C (65 - 90°F).

Attention must also be given to the inlet and outlet of the sludge settling basin. The velocity of the liquid at the inlet should not exceed 1 ft/sec, otherwise turbulence will occur and settling will be insufficient.

(3) Extended aeration treatment

The extended aeration process is a modification of the activated sludge process, the difference being that the aeration period is extended in order to oxidize not only the organic matter of the effluent but also the surplus sludge so that it is sufficiently stabilized for direct discharge to drying beds.

The most common version of this process which has found wide-spread acceptance in Europe for food-processing plants and for small communities is the oxidation ditch.

On account of their large volume and the high concentrations of active sludge oxidation ditches have a large buffer capacity, and are, therefore, capable of coping well with fluctuations in flow and load.

The layout of an oxidation ditch is shown in Figure 25.

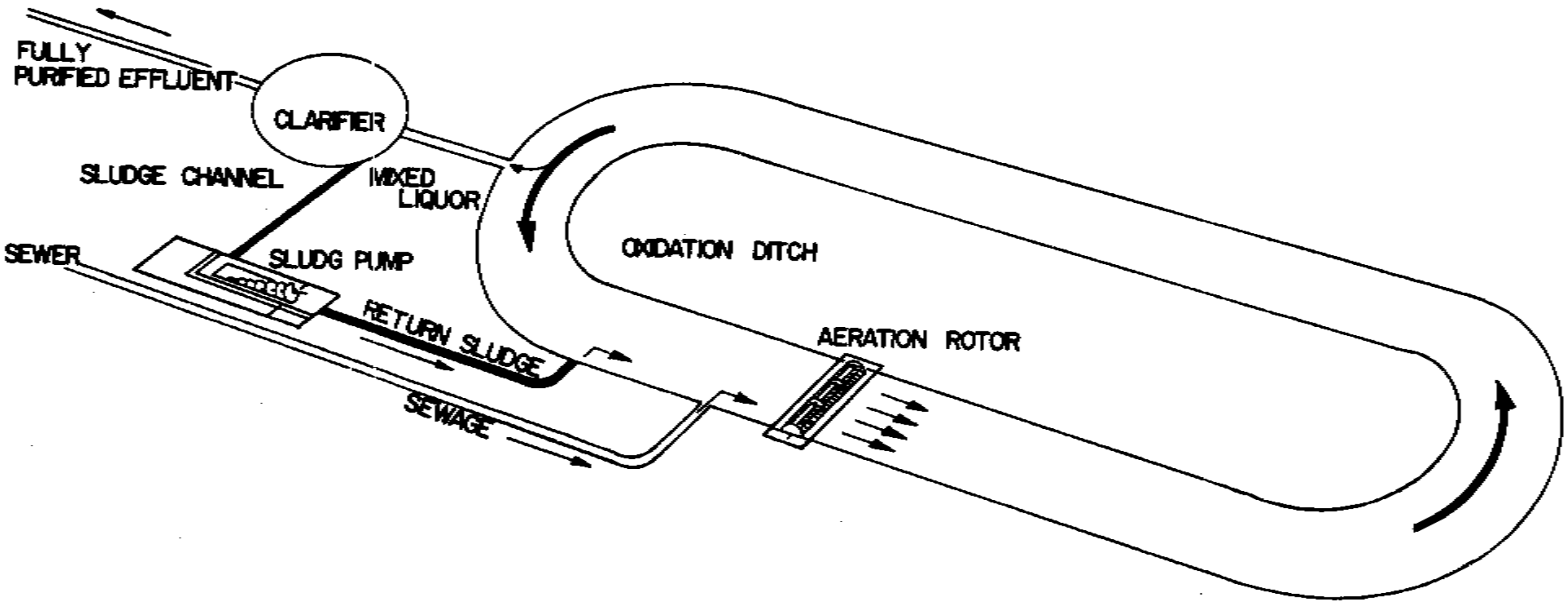

FIGURE 25

Lay-out of an oxidation ditch

Comparison of aerobic treatment processes

There is little information available on the aerobic treatment of milk wastes in South Africa; therefore, the results of a recent study, carried out in Germany are quoted(22).

TABLE 14

COMPARISON OF EFFICIENCY AND ECONOMICS OF BIOTREATMENT PROCESSES FOR MILK-PROCESSING WASTES(22)

	Two-stage biofilter	Activated sludge (tank)	Oxidation ditch
Reduction of BOD	92%	90 - 92%	89 - 98.5%
Reduction of $KMnO_4$	no results		69 - 90%
Sensitivity against fluctuation of flow and load	Yes	Yes, higher than two-stage biofilter	No
Retention time	-	1 day	1 - 4 days
Balancing tank necessary	Yes	Yes	No
Sludge settling tank	Yes	Yes	No
Surplus sludge disposal	Yes	Yes	No
Capital outlay plus operating costs (DPfg/kg milk intake)	0.115	0.17 - 0.33	0.08
Area required	Small	Small	Large

Biotreatment plants work best under conditions which are as constant as possible.

Because of the short retention time they provide biofilters and conventional activated-sludge plants require a 'balanced wastes' inflow. The oxidation ditch has the advantage of having sufficient buffer capacity to eliminate the need for a balancing tank.

Whereas biofilters can tolerate some fluctuations in the waste inflow at a reduced rate of efficiency, activated-sludge plant based on tank aeration are sensitive to changes in flow and load and require skilled operation and supervision. Extended aeration as can be practised with the oxidation ditch, requires less attention than the biofilter on the activated sludge tank aeration installation.

Because it is so simple to operate and because of its other advantages the oxidation ditch has found widespread acceptance in Europe for the treatment of effluents from rural communities, and for the treatment of wastes from milk-processing plants, abattoirs and fruit-canning factories.

Disposal by irrigation

Fat-free milk wastes, if kept fresh by aeration, can be successfully disposed of by irrigation, depending upon the nature of the soil and the vegetation. Spray-irrigation is preferable to flood-irrigation since a more even distribution is achieved. This method is especially suitable for the disposal of surplus whey which cannot be concentrated to whey powder or used as animal feed. The application rate on land under vegetation is higher than on bare soil. Fat present in the effluent can clog the soil and render it unsuitable for further irrigation.

The composition of dairy wastes disposed of by irrigation may be of importance to agriculture because of the possible effects some of the mineral constituents of the milk and its by-products may have on the physical and chemical character of the soil. The fertility of the soil is improved if it is irrigated with dairy wastes. The elements being beneficial to the soil in these wastes are phosphorus, potassium, calcium, magnesium and nitrogen. Excess sodium in the effluent, however, either as common salt (from cheese making) or as alkaline cleansers can cause deterioration in the physical condition of the soil. This may be overcome by the application of lime to the area. During dry seasons the addition of water to the dairy wastes is a valuable aid in maintaining a good growth of the pasture.

All milk-containing or whey-containing wastes tend to become sour owing to the conversion of lactose to lactic acid. Even when the irrigated effluent is neutral lactic acid may be formed by the bacteria present in the soil. Although an initial increase in the acidity of the soil, or a decrease in pH, is to be expected following irrigation, because lactic acid is subject to further decomposition, its acidifying effect is only temporary. To prevent the scorching of vegetation by dairy wastes, it is advisable to apply the milk wastes intermittently to the same portion of ground, allowing longer rest periods for more concentrated wastes. In the United States, spray irrigation is done on a return period of 4 to 10 days; for milk-cannery wastes a six-day cycle of heavy dosing, 8 - 10 cm (3 - 4 inches) per application is claimed to be typical. Results obtained in New Zealand have indicated that the maximum application for undiluted whey is about 110 m^3/hectare (10,000 gal/per acre) once every 14 days(23). Care is necessary to avoid double dosing of those portions of the area where there is likely to be an overlapping of wetted areas caused by variations in wind drift, or by leakages from pipelines during intermittent spraying.

One South African creamery which recovers all the buttermilk for drying, during the flush-season, spray-irrigated up to 1,350 m^3/ha/month (120,000 gal/acre/month) of diluted effluent on ground carrying lucerne with good results.

Experience has shown that crops of wheat, barley, oats, babala and lucerne can be raised with success on soils irrigated with diluted whey or effluents containing milk-solids provided the fat, which clogs the soil, has been effectively removed.

For most irrigation purposes perforated pipes are not satisfactory since dairy wastes tend to block the perforations; rotary sprinklers are preferred. The minimum nozzle size will vary with the type of pretreatment given, that is whether or not solids have been removed by sedimentation or screening. Preferably the nozzle should be at least 1/4 inch in diameter.

As it has been found that aluminium parts coming into contact with acid dairy wastes during spraying quickly corrode, these parts should be of copper alloy, or protected by an acid-resistant plastic lining.

For irrigation installations centrifugal pumps are more suitable than positive-action pumps since they provide a steady pressure; valves on the main pipeline or the branch lines can be shut off as required while the centrifugal pump is in operation.

4. CONCLUSION

Inadequate design of process equipment, accidental wastage of products, an unawareness of the actual water quality requirements for efficient unit operations, are all factors which contribute to an excessive fresh-water intake.

A fresh-water intake of less than 2 litre/litre (2 gal/gal) milk in milk-pasteurizing and bottling plants and 10 litre/kg (1 gal/lb) in cheese and butter manufacturing as already practised overseas, should be the target for dairy plants in South Africa.

Overseas experience has shown that this is a practical target.

The most promising steps for bringing about a reduction in fresh-water intake requirements are:

(1) recirculation of cooling water for condensing of refrigerants over cooling towers and proper cooling water treatment;

(2) closing the cooling water cycle in product cooling;

(3) reclamation and recirculation of cooling water for tinned and bottled products;

(4) adaptation of bottle-washing machines to suit South African conditions;

(5) the use of automatic shut-off valves on every water hose;

(6) segregation of 'clean' effluents free from milk-solids for collection and reuse as cooling water or floor wash-water.

Volume is the greatest cost factor in water and effluent treatment as it requires greater capacity of tanks, pumps, etc. Wilful wastage of milk products such as skim-milk, butter-milk or whey into the sewer during the flush season should be avoided on account of the high pollution load of these milk-products.

The best possible recovery of fat from rinse waters and drip milk should be obtained - running these wastes through a separator is strongly recommended.

Milk wastes are readily broken down by aerobic treatment processes.

Extended aeration appears to be the best method for the biological treatment of milk wastes.

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APPENDIX

THE COD METHOD

The oxygen demand of a waste may be determined by the chemical procedure detailed in the 'Standard Methods'(24) or by other methods. This chemical oxygen demand (COD) approximates to the 20-day or ultimate biological oxygen demand (BOD) of dairy waste. By using appropriate factors determined by experimentation, the 5-day BOD of the waste can be considerably shortened. The method is not intended to replace the standard 5-day BOD test, but it is of inestimable value as a quick method of controlling waste on the plant, as results are obtained in about 20 minutes. Details of the techniques of this rapid procedure, which were used in these studies on dairy wastes, are given below.

The 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 millilitres of concentrated H_2SO and 500 millilitres 85 per cent H_3PO_4. It is advisable to grind the dichromate to a fine powder. This is allowed to stand a few days with occasional shaking until the dichromate is in solution. To obtain a clear oxidizing reagent free of particles, filter the solution through glass wool or decant with care.

2. Potassium iodide solution made by dissolving 55.3 grams KI in 200 millilitres water.

3. Standard 0.05 normal sodium thiosulphate titrating solution prepared by dissolving exactly 12.41 grams $Na_2S_2O_3.5H_2O$ and making up to 1 litre 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 millilitres water and adding 75 millilitres boiling water.

The procedure is as follows:

1. Place exactly 50 millilitres of the dichromate oxidizing solution in a 500-millilitre Phillips beaker or Erlenmeyer flask. Use has also been made of 25 millilitre of solution with proportional reduction of other reagents and at reduced costs.

2. Add exactly 5 millilitres of the waste sample to the oxidizing solution. The strength of the waste should be between 50 and 1,500 mg/1 COD. If the expected COD is greater than 1,500 mg/1, dilute the sample, or add proportionately less and make up with water to give 5 millilitres.

3. Place on hot plate and heat uniformly so that the 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 millilitres of distilled water and cool again in water bath.

6. Add 10 millilitres of the potassium iodide solution and titrate immediately against the standard 0.05 normal thiosulphate solution, adding starch near the end point. The colour change is from dark blue to pale blue green. Ferroin may also be used as an indicator.

7. The chemical oxygen demand in parts per million or milligrams per litre is equal to 80 times the difference in titration in millilitres between the water blank and the sample. N.B. If the original waste was diluted for testing, this must be taken into consideration. The calculation follows:

$$\frac{D \times 0.05 \times 8}{5} \times 1000 = D \times 80 = \text{COD}$$

D = difference in titration between the blank and sample;
0.05 = normality of the thiosulphate;
8 = milligram-oxygen equivalent to 1 millilitre normal thiosulphate;
5 = volume taken for oxidation;
1000 = conversion value to obtain milligrams per litre or parts per million.

The result approximates to 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 requires 1.25 grams of oxygen for complete oxidation.