FACTORS ASSOCIATED WITH THE CLEANING AND STERILISING OF FARM DAIRY MILK PIPELINES

A thesis submitted to the University of Glasgow for the degree of Master of Science in the Faculty of Science

by

ALBERT LESLIE WIGGINS
B.Sc. (Agric.)

Department of Dairy Technology,
The West of Scotland Agricultural College,
Auchincruive, Ayr.

November, 1967

ACKNOWLEDGMENTS

I wish to thank the Governors and the Principal of the West of Scotland Agricultural College for the facilities provided to permit this study to be made. Grateful acknowledgment is made to Dr. R.J.M. Crawford and members of the staff of the Dairy Technology Department for their helpful criticism and assistance. I am indebited to Miss M.J. Orr of the Bacteriology Department for her advice and help and to members of her staff for assistance with some of the bacteriological analyses. The help of the farmers who permitted the investigational work to be carried out on their equipment is also acknowledged.

CONTENTS

INTRODUCTION

The traditional method of milking cows in the South West of Scotland has been developed around the byre where originally the milking was effected by hand, and, more recently, by machine. The use of the byre not only permitted the cows to be sheltered during inclement weather but also allowed the milking operation to be carried out with the cows remaining tethered in the same stall.

Whilst such a system was extremely prodigal of labour, since the milk had to be carried in buckets over comparatively long distances, it persisted without change until the comparatively recent introduction of refrigerated farm milk tanks and the conveyance of milk from the milking point to the cooling equipment by pipeline.

There has been a marked increase in the number of pipeline installations in the United Kingdom during the last few years since such a system of milk handling offers considerable economies in labour as well as providing a simple, efficient and more attractive method of transferring the milk from the cluster direct to the milk cooling room, usually a refrigerated farm bulk milk tank.

In 1959, nearly 7% of the dairy farms in England and Wales had pipeline milking plants (Cuthbert, 1961) and by

1964 this proportion had increased to over 13% (Federation of United Kingdom Milk Marketing Boards, 1966).

In Scotland the development of the pipeline milking systems has taken place in a different manner than in the rest of the United Kingdom where the pipeline installations often preceded the incorporation of refrigerated milk tanks. In Scotland, however, many refrigerated farm tanks were installed before the pipeline. This was due to two principal reasons. Firstly, the method of cleaning. Early pipelines were installed in milking parlours where it was necessary to dismantle them completely for cleaning. With the comparatively short lines involved, this was not a great problem but it would have been quite impracticable with pipelines situated in byres which are often of considerable length. With the introduction of methods of cleaning in place, however, such dismantling became unnecessary and the practicability of installing pipelines in byres became apparent. The second reason lay in the method of sterilisation which was permitted for dairy equipment in Scotland. Chemical sterilisation was not permitted in Scotland until 1962 when a report (Model Dairy Bye-Laws, 1961) was published by the Committee which had been set up to prepare new model dairy bye-laws in Scotland under the

Milk and Dairies (Scotland) Act, 1914. The use of approved chlorine sterilants was recommended by this Committee and this was accepted by the Secretary of State for Scotland. Each local Authority was therefore requested by the Secretary of State to amend the existing bye-laws to permit chemical sterilisation using approved chlorine containing compounds as an alternative to steam or scalding water for the sterilisation of farm dairy equipment. This was subsequently implemented in the Milk and Dairies (Scotland) Act, 1965. Before this, therefore, any pipeline installations would have had to have been sterilised by steam or boiling water, a difficult and uneconomic method. As soon as the use of approved chemical sterilants was permitted in Scotland, the advantages to be obtained from cleaning in place encouraged many producers to link up the farm refrigerated milk tank, which in many cases had already been installed, with a pipeline system.

There are two principal systems of milking which incorporate pipelines - milking parlours and that system known as "round-the-shed". On Scottish farms, if the byre is of modern construction, or in good structural condition, then the installation of a "round-the-shed" system of milking would be more attractive. With this type of installation, although the cost may be high in relation to the conventional bucket system, which it replaces, the reduction in the labour requirements for the carriage of the milk from the byre to the dairy, the elimination of the milking bucket, the added simplicity of the cleaning and the integration of the pipeline with the bulk tank have provided the encouragement for the many installations which have now been made.

The number of the pipeline installations in Scotland has markedly increased since the introduction of the bulk milk collection schemes in Scotland. The first such scheme in Kirkcudbrightshire commenced in 1954.

The majority of the "round-the-shed" installations, as distinct from milking parlours, are in the South West of Scotland, which area produces the greatest volume of milk. The comparable number of installations have been given by the Scottish Milk Marketing Board, (1966).

	South West Scotland Ayrshire, Dumfries, Kirkcudbright, Lanark, Renfrew & Wigtown.	Other Counties
Milking parlours	68 (0.94%)	239 (3.3%)
"Round-the-Shed"	444 (6.2%)	245 (3.3%)

The amount of investigational work which has been published on pipeline cleaning is not extensive, and much of this has been carried out during the last few years. The majority of published work is from North America, and of that published in this country, much deals with the cleaning of pipelines in creameries. Other than bacteriological studies, work which has been published in this country deals primarily with milking parlours. This is not so applicable in the majority of dairy farms in South West Scotland, where due to the greater adoption of the "round-the-shed" system, the pipeline is considerably longer than in a parlour, often several hundred feet. This would tend to present different cleaning problems about which little has been published.

A study has been made of the relevant literature of the different factors which can contribute to the efficiency of the cleaning of the pipelines - temperature, turbulence, entrained air, time of circulation, corrosion, equipment design and operation and detergent composition.

Investigations have been carried out on the effect of different temperatures on qualitative and quantitative aspects of the bacterial populations of pipelines; the relationship between the total colony counts and the composition of the bacterial flora; the effect of detergent composition in relation to the temperature of circulation; and the loss of heat from the circulating solutions from the pipelines.

INSTALLATION

Development, design of, and materials used for milking installations

In the late 1920's a number of pipeline milkers or 'releaser plants' as they were called, were installed in specially built wooden stalls or in small cowsheds. The milk was discharged direct into cans by a double compartment 'flap valve'. Cleaning had to be effected by means of manual scrubbing and for this reason the system was not accepted as being practical in the cowshed. In addition, the introduction of milking parlours about this time presented a satisfactory alternative to those producers who desired to re-organise their milking methods and reduce the labour requirements.

As has already been stated, the method of dairy farming in South West Scotland did not readily permit the adoption of the parlour system, but in the period 1947-49 a system was introduced which consisted essentially of vacuum operated pick-up points for the transfer of milk from the byre to the dairy. The milk was discharged from the milking buckets into cans in the byre and the 'suck-up' line, usually supplied in 6 ft. lengths to facilitate manual cleaning, was connected to a milk lift which was mounted directly over the cooler. When the can had been emptied of milk the suck-up pipe was sealed by a float which rose, permitting the vacuum to operate only when further milk was tipped from the milking buckets.

From the introduction of the milk lifts, it was only a question of time before the milk lift was extended to circuit the byre and was fitted with stall cocks, so that the milk was drawn by the vacuum through the pipeline to the releaser jars, where it was discharged either to a refrigerated milk tank or over a surface cooler to the milk cans. Not until the development and official acceptance of approved chemical sterilants in The Milk and Dairies Regulations,(1949)in England and Wales which was re-enacted in the Milk and Dairies (General Regulations) 1959 (S.1.277) was the way opened for the introduction of extended milk pipelines into byres and the first were installed about 1960. Since that date, this type of installation has become increasingly more common.

Comparative investigations have been carried out to determine whether pipeline installations could be operated to produce milk of a similar hygienic quality to that produced by other systems of milking, including milking buckets or pipelines which have been disassembled and cleaned by hand. (Stephen, 1955; Witzel, 1953; Downing, 1953; Phillips, 1962).

Alexander, Nelson and Ormiston (1952) carried out comparative work on the bacteriological results of milk obtained from four different systems of milking - conventional bucket plant; combine plant with conventional filtering, in-can cooling and pipeline dismantled for cleaning; combine plant with in-line filter, in-can cooling and the pipeline dismantled for cleaning; and "cow to can" with stainless steel or glass pipeline. There was no significant difference in the bacterial quality of milk between those installations where the pipelines were dismantled and where they were cleaned in place. They observed, however that some variation in milk quality occurred between different operators where the pipelines were cleaned in place.

Parker ,Elliker, Nelson, Richardson and Wilster (1953), indicated that a properly designed and constructed pipeline could be maintained in as hygienic condition as those which were regularly dismantled. Their observations were based on the bacteriological results of swab tests on the pipelines.

Fortney, Baker and Bird (1955) showed that in place cleaning of stainless steel pipelines was at least as effective, both bacteriologically and physically, as dismantling and hand cleaning.

Basic considerations in the design, installation and operation of pipeline milking equipment are given by National Agricultural Service (1967a), (1967b).

The most usual type of installation is in the form of a loop in the case of a double sided byre, being connected across the end of the byre. Risers, or inclined pipes, are used to carry the pipe above any doorways. Although in some installations only air passes through the cross piece, in others, milk passes, and, owing to the difference in levels, this can be a possible source of trouble. This can be prevented by fitting a butterfly valve at the end of each side or in the middle of the crossover. Either position would have the effect of applying the direction of vacuum in one way only from the cross over, but, at the same time, the incorporation of such valves could in themselves be an additional cleaning hazard.

Where the installation is fitted in a byre in which the standings are only on one side, the milk pipeline is continued through the byre towards the milkroom and is supplemented by another which is parallel to it, and is joined at the distant end by an 180^{O} bend. The latter pipeline is only used to complete the cleaning circuit and a butterfly valve is normally fitted at the farthest point, thus isolating it from the milking line whilst milking is in progress. An alternative arrangement is suggested from North America (University of California, 1964) where, under similar conditions, stall cocks are fitted on the two pipes, thus utilising both pipelines. Such an arrangement would, however, require both pipes to enter the releaser to permit the vacuum to be applied to both arms.

Between each pair of cows is a provision on the pipeline for the connection of the rubber milk tube to the clusters, these being available in different designs from several manufacturers..(see Plate 1 - 3).

There are three main types of stall cock connection in use in the South West of Scotland, each with its own particular disadvantage in cleaning. In routine cleaning of the pipeline, attention is rarely paid to the inlet of the stall cock and this is often found to be a source of infection. Where rubber gaskets are used in the stall cock connection these rapidly deteriorate and are often a source of bacterial contamination.

Clegg (1956) pointed out that as the difference between the cleanability of rubber and metal was realised it became apparent why chemical sterilisation was less effective on rubber than on metal surfaces. The rubber loses its smoothness with use, and apart from any faults inherent in manufacture, present a rough surface which allows milk solids to accumulate. Whilst heat can penetrate such deposits they are not removed by ordinary washing. Although these observations were concerned with the cleansing of milking machines, they are equally applicable to the rubber connections found in "round-the-shed" installations.

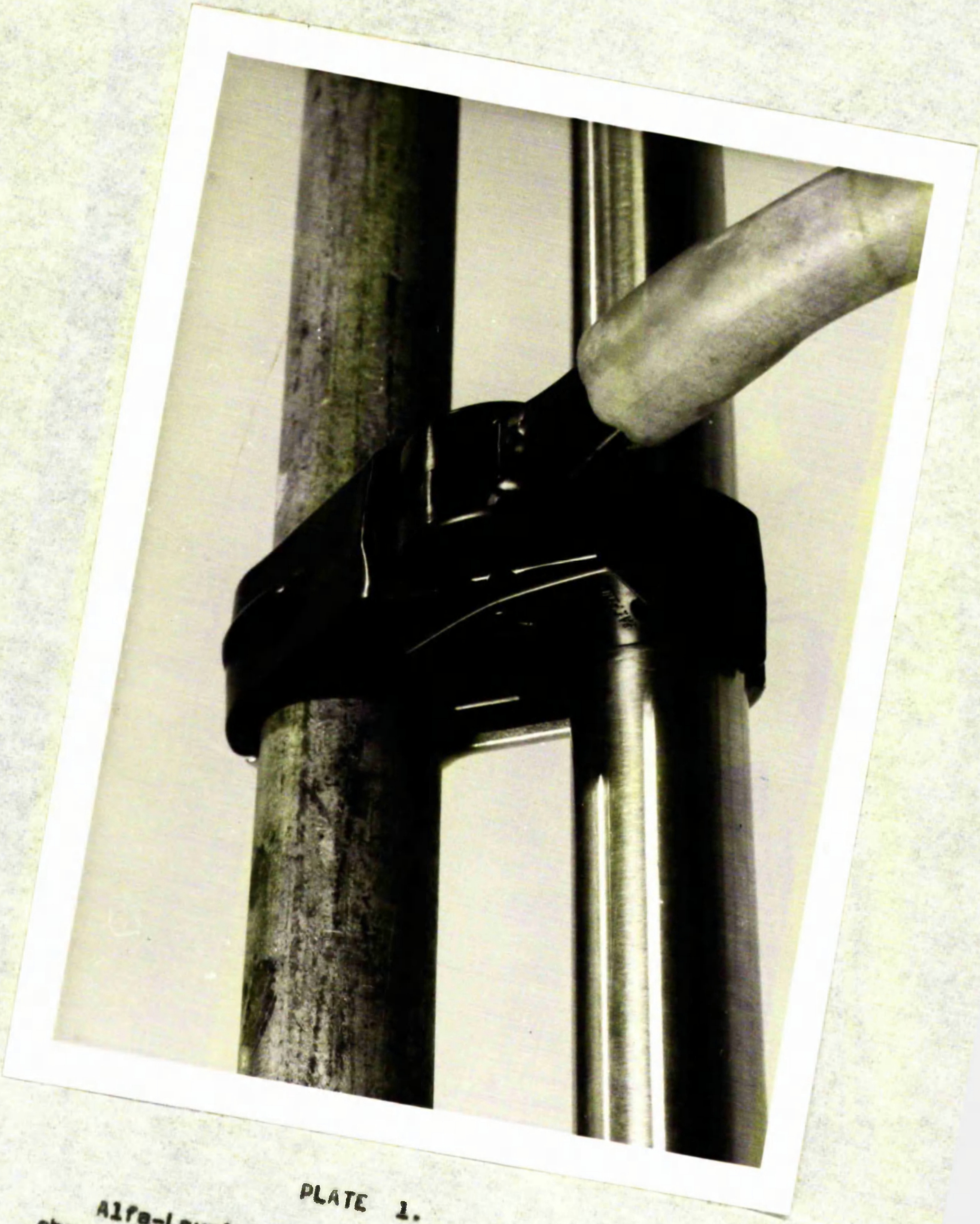

PLATE 1.

Alfa-Laval pipeline connection for 'round-the-shed' milking installation.

PLATE 2.

Fullwood pipeline connection for 'round-the-shed' milking installation.

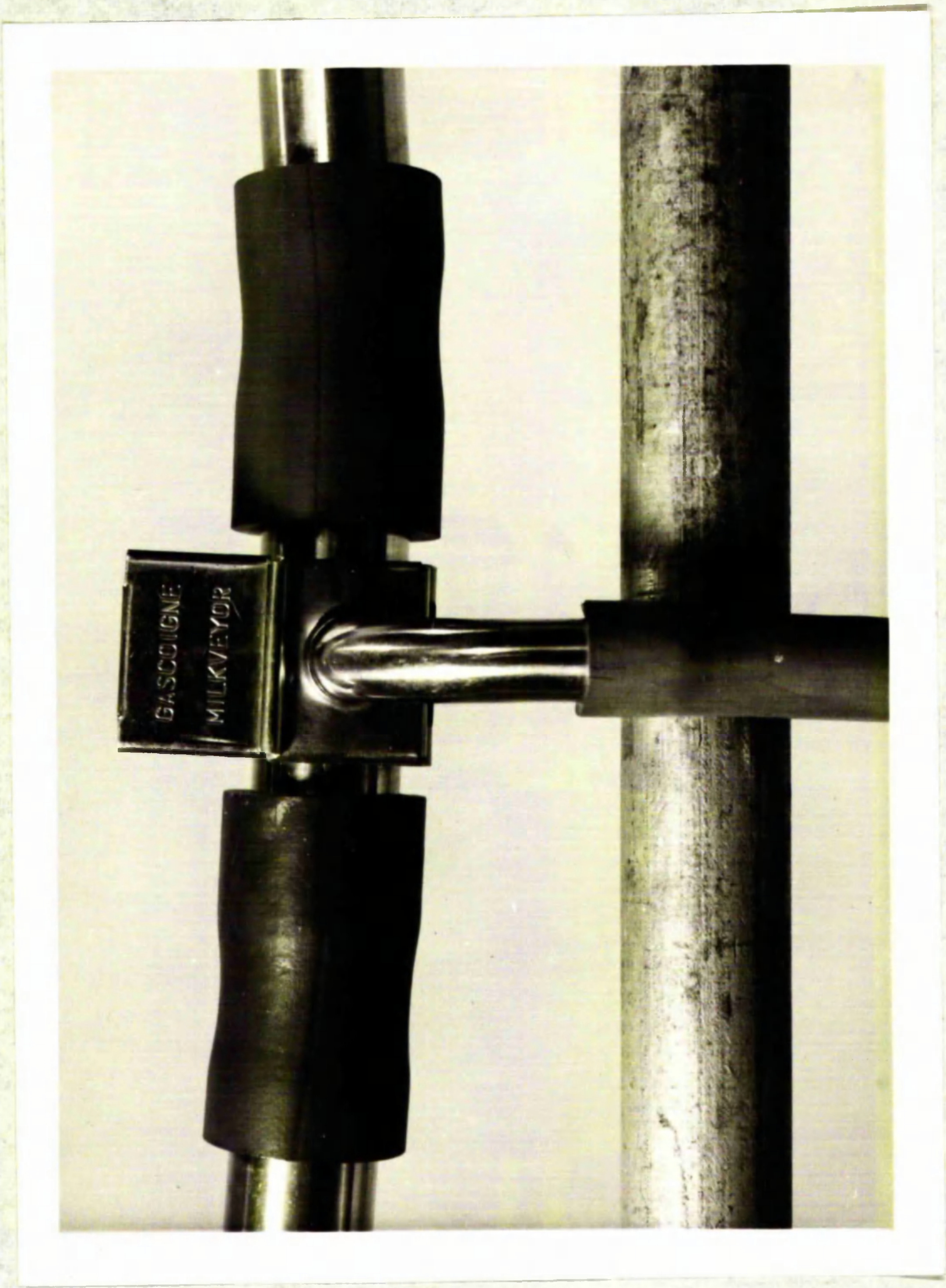

PLATE 3.

Gasgoigne pipeline connection for 'round-the-shed' milking installation.

The stall cock connection must be so fitted that the tube from the milking cluster enters the top half of the milk pipeline. This is in order to maintain a vacuum between the pipeline and the cluster, and to prevent the back flushing of milk. Were the pipeline entry at the bottom, there would be considerable vacuum disturbance when milk from other units flowed across the milk inlet. Whilst the fittings are designed with a top entry it is possible that, during use, the outlet be twisted downwards. This results in milk soiling the inlet valve and this should therefore receive additional cleaning treatment.

The pipeline is continued to the milkroom carrying the milk and entrained air away from the clusters to the receiver jar where the air is extracted by the vacuum pump and the milk discharged either to the refrigerated tank, or over a surface cooler and into the cans.

In some installations only one end leads to the receiving jar, the other joining the return pipe to the milkroom before it leaves the byre. In others both ends of the pipe are joined at the releaser by a T-piece. It would be better for both ends of the milk pipeline to enter the jar since any junction of the two pipelines outside could result in the pipeline flooding, whereas if the vacuum is applied to both ends of the loop, the milk could be discharged more quickly.

The receiver, or releaser jar, is a glass container, the outlet of which is connected to a sanitary milk pump. The earliest milk releaser jars were glass cylinders with stainless steel plates on either end. These were sealed off by gaskets and held together with long tie rods. The gaskets were large and subject to considerable soiling and offered crevices for the retention of infection. All glass receiver jars have been redesigned. These jars are robust, sanitary, possess high resistance to thermal shock and exhibit complete resistance to detergent attack. The glass jar can be suspended from a spring loaded micro-switch. The milk enters the jar at the top and the micro-switch is adjusted so that the pump operates when a certain weight of milk is in the jar, switching itself off when the milk drops to a certain predetermined level. In another type of installation the micro-switch is replaced by two probes of different lengths placed in the jar, and the pump operates when the level of the milk permits contact to be made between the two probes. Another type of installation utilises a vacuum-operated diaphragm milk pump which is continuously operated and this continuously evacuates the receiver jar of milk. In all cases, the pump forces the milk through a non-returnable valve to a filter - either an in-line filter where the milk is filtered under pressure, or through a 'D' pan & and thence to the refrigerated milk tank or the milk cans.

Theil (1962) describes the early attempts in the circulation cleaning of the releaser jars which necessitated the complete filling of them in order to cover all milk containing surfaces. This involved the use of a large volume of liquid which for reasons of economy had to be retained from day to day and was therefore circulated cold. A device was developed which deflected the cleaning solution across the underside of the jar and down the inner walls. This permitted a more efficient washing action of the jars with a reduced volume of liquid.

The milk pipelines are either 1¼ in (31.7 m.m.) outside diameter of 18 gauge (1.2 m.m.) stainless steel or 1¼ in (31.7 m.m.) resistance glass tubes with

0.12 in. (3.0 m.m.) wall thickness. In a few instances plastic tubes have been used.

The type of stainless steel pipes for the milk transfer exhibit a high degree of mechanical strength, corrosion resistance and blemish-free surface. Since this material can withstand the far more drastic chemical treatment than is often necessary for the removal of more stubborn deposits, stainless steel pipelines are more common than other materials. Allum (1964) has discussed the use of stainless steel for dairying equipment. Stainless steels can be divided into two classes according to its nickel content and its effect on the physical structure of the steel. The martensitic steels may contain up to 2.5% nickel and are similar to carbon steels in that they are magnetic and their mechanical properties are influenced by heat treatment. Austenitic steels, the type used for the manufacture of industrial equipment, are non-magnetic and can only be hardened by cold work. A defect which can occur in the range of austenitic steels is that known as "weld decay". During the heating or cooling encountered during welding, chromium carbides are liable to come out of solution and are precipitated at the grain boundaries. In this condition they are readily attacked by chemicals and intercrystalline corrosion may rapidly occur.

This defect is eliminated either by reducing the carbon content of the steel or by adding metallic elements which readily combine with the carbides and prevent their precipitation. Such steels are 'stabilised' by the addition of titanium and columbium. Both types of austenitic steels are used for the manufacture of milk piping. Allum (1964) stated that the usual steels for pipelines are EN 58A, B or J (A.I.S.I. 302, 321 or 316) of which EN58A is not stabilised.

Pipes can be either solid drawn, in which the finished pipe is seamless, or it can be made longitudinally, butt welded, rolled and formed. With the latter method of manufacture, the internal weld bead is removed and the internal surface fully polished. The standard grade of polish is mirror finish to the internal surface. This internal polishing limits the length of pipeline available to not more than 16 feet.

Pipe lengths, of a maximum length of 10 feet, are connected together by rubber sleeve joints, except when the actual stall cock is of rubber, when this also acts as a joint. With this type of installation the pipes are cut to the appropriate length between each pair of standings. With the other type of stall cocks a hole can be drilled in the pipeline, and the stall cock fitting clamped to the outside. Bends are formed by the fitting of rubber elbows, as are T-joints.

Where the milk flowing in the pipeline is under pressure rather than under vacuum, as is the case on the discharge side of the pump - from the pump to the refrigerated tank or the milk cooler - these sleeved joints are replaced by a screwed joint on a smaller (1 in.) (31.7 m.m.) bore stainless steel pipe or the rubber sleeve is reinforced by a clip. The screwed joint is either metal to metal or else a thin rubber gasket is incorporated. This type of joint can give more trouble associated with crevices and faulty rubbers than the rubber sleeve joint employed with wider bore pipes. In addition, the narrow bore pipe has a less well polished internal finish and therefore presents a more difficult surface for adequate cleaning and sterilising.

Whilst individual components of a pipeline milking installation have been well designed, unless they are correctly installed such systems can give rise to serious difficulties not only in cleaning and sterilisation but also in operation. This is often found to be the cause of unsatisfactory operation of installations in South West Scotland by specialist advisory officers (West of Scotland Agricultural College, 1966). Murray & Downey & Foot (1962) in a survey of pipeline milkers in Northern Ireland found that some plants, whilst of satisfactory design, had not been correctly installed and these defective installations gave rise to difficulties in cleaning. Neither the use of chemicals nor heat gave satisfactory results if the plant had certain features of poor design or if the installations were faulty. Johns (1962) found that satisfactory cleaning in place is primarily dependent on satisfactory design of equipment, although proper installation and adequate cleaning procedures are also important. Maxcy (1966) also observed that the design characteristics of equipment should be tested before it is introduced into commercial installations.

The most usual defect is that little attention has been paid to the fall of the pipeline which either has no fall or else it falls the wrong way. It is normal installation practice for the milk pipeline to be attached to the vacuum pipe, and, since it is good practice for the latter to fall away from the vacuum pump to prevent moisture being drawn into the pump, it follows that the milk pipeline will also fall away from the vacuum pump which is often situated near the milk pump.

The slope of the pipeline is a major factor affecting vacuum fluctuations due to the flooding of the pipeline with milk. The pipeline should be installed so that the milk is conveyed by gravity to the lowest level of the installation. It is at this point that the receiver jar should be installed. The milk will then flow naturally towards this discharge point. A minimum pipeline slope of 1:80 is advisable, although 1:240 has also been quoted as being the desired minimum. (Society of Dairy Technology, 1959). The latter figure, however, refers to creamery pipelines where there would be correctly designed expanded or welded fittings which would not present such a hazard. Such fittings are quite expensive and are therefore not incorporated in farm pipeline systems. Cuthbert (1960) observed that farm pipeline installations do not achieve the smooth, uninterrupted flow which are now commonplace in the processing plant. Furthermore, plentiful supplies of water, heat and pumping facilities cannot be justified economically in farm installations.

It is difficult to obtain this satisfactory slope of 1:80, as is indicated by the University of California (1964) unless the floor slopes towards the dairy. Unfortunately, if the floor has a fall it is away from the dairy and this would result in the milk pipeline having a slope the wrong way. Where the pipeline is installed in more than one byre, discrepancies may occur between the level of milk pipeline in the different byres, and their relationship with the position of the refrigerated bulk milk tank.

The siting of the refrigerated farm milk tank is one factor which exercises considerable influence upon the fall of the pipeline. Many installations have been made and have experienced considerable operational and cleaning difficulties which, upon investigation have been shown to be due to the milk tank room being unsuitably placed which has necessitated the pipelines being fitted with the fall in the wrong direction. Installations have also been attempted where the pipeline is fitted around several byres, where, due to their relative levels and the length of the pipeline involved, this system of pipeline milking should not have been encouraged.

In many installations it has been found that the capacity of the pump is not sufficient and this results in operating difficulties as well as less efficient circulation cleaning. Fyfe and McFarlane (1965)in an investigation on the efficiency of milking equipment in South-West Scotland found that the majority of installations examined had inadequate vacuum pump capacity. McFetridge (1959)and Hall (1953) showed that many of the milking installations are in an unsatisfactory state of repair.

Clough (1965) stated that inadequate vacuum pump capacity is the most common cause of mechanical inefficiency in milking installations. It is difficult to specify vacuum requirements for pipeline milking installations as they vary considerably between makes and also within one make of equipment. A figure of at least 5 ft^3/min. of free air/unit is often given. This figure, however, does not take into account many other factors which would seriously influence the consumption of air. Differences in conditions; additional equipment such as milk lifts; operating techniques and standard of equipment maintenance will cause wide discrepancies, and all contribute to wide variations in vacuum demand. It is impossible to pre-calculate air leakage for any particular installation because of these factors. The only accurate assessment can be made by direct measurement of the air consumption of the installations. Such a measurement would rapidly indicate any discrepancy in pump capacity and excessive loss due to inefficiently maintained equipment.

There has been a development in North America of welded milk pipelines where the joints, potentially a source of infection, are eliminated. The use of such pipelines could improve hygiene and eliminate the chance of air leaks through couplings as well as turbulence problems caused by imperfections of the inner surface of the pipeline. Such a development would not have been possible without the improvements in cleaning systems and detergents which make periodic dissembly and inspection unnecessary. Maxcy and Shahani (1961) studied the effectiveness of cleaning welded pipelines both with a laboratory installation and commercial systems over 2 years, and found that this type of pipeline was satisfactory.

Havighorst (1951) described the manufacture, installation and cleaning of welded milk pipelines. A study of the use of welded pipelines made by Olson, Brown and Mickle (1960) showed that they were quite satisfactory.

Newer installations using larger bore pipelines of up to 2 in. diameter which prevents the flooding of a pipeline with milk, have been reported (University of California, 1964), Whittlestone, Beckley and Cannon (1964). Whilst such an installation permits a more rapid and effective removal of milk, it does present greater cleansing problems.

In order to obtain the velocity necessary for efficient cleaning which is generally recommended as 5 ft^3/ sec. the comparable flow rate of 2 in.pipeline would be approximately equivalent to 2,550 gall/hr. which is considerably more than that for a 1½ in. pipeline which is approximately 900 gall/hr. Such a cleaning system would require a larger vacuum producer, if the vacuum is used for the circulation, as is invariably the case in installations in Great Britain.

Use of glass for installations

The transparency of glass is an additional advantage for farm milk pipelines in that it offers a direct visual check on the milk which is being conveyed through the pipelines as well as the internal cleanliness. This opportunity of a rapid visual check of the internal surfaces of the pipeline does permit the early removal of any milkstone deposits which could well pass unobserved with stainless steel pipelines until its presence resulted in unsatisfactory bacteriological results. Bruce (1959) states that glass shows little tendency for the formation of films of scale or corrosion products. The smooth surface of the glass pipeline is highly resistant to the deposition of such materials. Broadly speaking, the main resistance to corrosion of glass is the hard smooth surface, and if this has been removed the rate of attack would tend to increase.

Glass requires only reasonable care in handling during installation and operation. It can withstand heat shock and repeated high temperature changes up to 200°C and can therefore be safely sterilised by hot water or live steam. The low expansion of the glass also minimises the trouble which can be associated with pipeline installations since no buckling will occur as a result of temperature changes.

The characteristics and properties of glass as a material of construction are discussed by Bruce (1959) whilst Burton (1957) described its application for pipelines and process plant.

Bruce (1959) stated that the chemical endurance of any glass - that is, its resistance to chemical attack - is influenced not only by the character of the corrosive fluids in contact with the glass, but also the composition of the glass as well as temperature and liquid velocities. With borosilicate glass, from which milking equipment is manufactured, the rate of attack by water and acids can be considered negligible, with two exceptions. Saturated steam above 150°C will react with the alkaline components of the glass, but up to this temperature the rate of attack is so low to be insignificant in practice. The acids which attack glass are hydrofluoric acid and strong phosphoric acid, the rate of attack by the latter being less severe than that of 5% sodium hydroxide solutions. Generally, the attack by caustic solutions is cumulative and the main resistance to corrosion is the hard smooth surface. Glass equipment can handle both dilute (15%) sodium hydroxide, and also phosphoric acid, concentrated if cold and up to 40% if hot (McEwan, 1967). Such extreme conditions, however, would not be encountered under normal operating conditions so that it can be assumed that glass is relatively inert to any chemical attack, and it can be rightly claimed that glass offers complete resistance to attack by detergents or acid descalants during repeated cleaning cycles.

In the recommendations given by the British Standards Institution (British Standard Specification 2598, 1953) the mechanical strength of glass pipelines are based on working stress of $500/in^2$. Such pressures, however, are greatly in excess of any likely to be set up in milking installations, but pipelines possessing such tensile strength would be of more robust construction than has been usually associated with glass. Since glass, whilst having an almost unlimited compressive strength, breaks as a r esult of limiting tensile stresses at its surface, the condition of the surface has an important bearing on its strength.

Glass piping is manufactured by drawing the molten glass from an annular forming mechanism and the resultant pipe is subjected to further processing such as grinding and polishing. The resultant quality of such glass equipment is high and free from any surface flaws which would affect its mechanical strength.

The two thermal properties possessed by glass equipment - linear expansion and thermal conductivity - are of importance because of their effect, the former on thermal endurance, the latter for conductivity. It is pointed out, Bruce (1959), that both properties are affected by the chemical composition of the glass, expansion being dependent largely on silica and boron content, conductivity varying to a smaller extent with composition.

Thermal endurance is a term used to describe the property of glass which permits it to accommodate sudden temperature changes without damage. Borosilicate is an example of such heat-resistant type of glass. Thermal endurance is influenced directly by its tensile strength and inversely by its coefficient of expansion and its modulus of elasticity. Of these, only the expansion coefficient varies significantly with composition, and hence thermal endurance it regarded as being inversely proportional to the expansion coefficient.

Comparable expansion coefficient of materials used for the manufacture of pipelines

(Bruce, 1959)

Material	Linear coefficient of expansion $\times 10^{-7}/^{\circ}C$ ($25^{\circ}C$ - $300^{\circ}C$)
borosilicate glass	32
cast iron	100
18:8 stainless steel	170
aluminium	250
copper	170

Comparable thermal conductivity of materials used for the manufacture of pipelines

(Bruce, 1959)

Material	Coefficient of thermal conductivity B.t.u./h/ft^2/$^{\circ}F$/in. thickness
borosilicate glass	7.8
cast iron	360
18:8 stainless steel	110
aluminium	1,440
copper	2,610

These figures would be of interest only were these materials to be in the construction of heat exchangers where the conductivity characteristics are of paramount importance. They do indicate, however, that the marked differences in thermal conductivity of glass and stainless steel can be of importance when these materials are used for the construction of farm milk pipelines insofar as heat loss of cleaning solutions are concerned. This aspect, however, is discussed elsewhere.

Standards for glass pipelines and fittings have been laid down by the British Standards Institution (British Standards Specification 2598, 1955) but the more common size used for milk lines are of 1 in. or $1\frac{1}{2}$ in. internal diameter (25 m.m. or 40 m.m.) both with a wall thickness of approximately 0.12 in. (3 m.m.) Connections between pipe-lengths as for stainless steel pipelines are with rubber sleeve connections although connections are available which are the subject of a British Standard Specification (B.S.S. 2598, 1955). The sealing is effected by an interface gasket located in place, in relation with the pipe bore by retaining bolts which hold tapered backing flanges passing through it. The choice of material for use in conjunction with glass pipeline is obviously of importance to its use. Whilst polytetrafluoroethylene has many applications as a gasketing material since it possesses exceptional chemical stability, the usual material for milk and other food products is white sweetened rubber. A coupling which has been developed for the jointing of glass sulphuric acid coolers (Messrs. Q.V.F. Ltd., Fenton, Stoke-on-Trent) would appear to be neater and more adaptable than the coupling previously described. The coupling consists of a moulded rubber sleeve which fits over the tapered ends of the pipeline. The sleeve is backed by a stainless steel gaiter which is secured by two worm drive clips. Such couplings can only be used, however, where the pipeline is a continuous run. Where the pipeline is interrupted by stallcock fittings such couplings could not be used although they would appear to offer an advantage over the rubber sleeve fittings in that the joint could be made more hygienic.

Improvements in glass milk pipeline equipment is discussed by Quiet (1963) who pointed out that earlier glass pipelines did have room for improvement. An early investigation was set up at Cornell University which showed that glass lines could be kept as satisfactorily when cleaned in place as could pipelines made of other materials cleaned by disassembly and conventional methods. There were, however, some defects which were noted. If the ends of the glass pipeline did not precisely match, the system would not drain properly. In addition the gaskets which were used tended to retain soil. Quist (1963) described how these difficulties were overcome as well as those found in milk receiving jars and milk cocks. Moore, Tracy and Ordal (1951) investigated whether stainless steel and glass pipelines could be satisfactorily cleaned in place by the circulation of acid and alkaline detergents, and sterilised by the circulation of water at 180°F. Bacteriological examination was made by taking samples of milk at the inlet and outlet of the line, and by swabbing the cleansed line. The system was used over a period of 5 months and at the end of that time it was found that from a hygienic viewpoint, a permanently installed pipeline of either stainless steel or glass was found to be satisfactory.

Four different polished finishes of stainless steel were used in this investigation and there was found to be no difference between them and the glass.

A report by Masurovsky and Jordan (1958) gave the results of studies on three different types of glass and they found that all the glasses studied were found to be highly cleanable.

Fortney, Baker and Bird (1955) used bacteriological techniques to compare the relative cleanability of glass and stainless steel and found that there was no significant difference between these two materials.

Fleischman and Holland (1953) compared the relative efficiencies of compounds used for the cleaning of glass pipelines. Whilst quaternary ammonium compounds were unsatisfactory, the hygienic quality of pipelines which had been sterilised by either hot water or chlorine was better than that of stainless steel pipelines which had been dismantled and cleansed manually. Window (1953) discussed the use of glass pipeline for conveying milk and Shearing and Feldo (1953) investigated the effect of different velocities and temperatures of the cleaning solution on the cleaning of glass pipelines. It was found that water at 190°F or solutions containing 200 p.p.m. available chlorine satisfactorily sterilised glass lines.

The use of glass pipelines offers advantages over the more usual application of stainless steel in farm installations and there does appear to be a wider use of glass for this purpose. The limiting factor appears to be one of cost rather than strength and suitability of the material. Whilst glass costs less per foot run than stainless steel, the stall connections have been designed, with one exception, using stainless steel pipeline. Therefore, where glass is used, there would be an increase in the number of rubber sleeve connections which would not only add materially to the cost of the installation but also to the difficulty in cleaning.

Cleaning

General

The method of cleaning the milk lift was originally by the disassembly of the pipeline, followed by manual brushing, but latterly it was cleaned by drawing a detergent solution through it from the byre by vacuum to the can, discharging the solution in the milkroom. After rinsing the pipeline in a similar manner, the pipeline was sterilised by steaming. Later, a system of cleaning in place was devised by the installation of another pipe parallel to the milk line and connected to it by a temporary connection, and the cleaning solution drawn through it by the application of the vacuum. In Scotland the use of chemical sterilants was not permitted until 1962, so that sterilisation could only be effected by steam or hot water before that date. Originally the pipeline systems could only be cleaned by disassembly and this factor precluded the adoption of this system of milking until a method of cleaning in place had been developed and shown to be satisfactory. The cleaning solutions were drawn through the milk pipeline which was so arranged that it formed a complete circuit with the vacuum applied to one end. The circuit was completed by the incorporation of connecting lengths of pipeline which may have or may not have been isolated during the milking either by disconnection or by the incorporation of butterfly valves.

The cleaning solutions were generally drawn through the system by the vacuum being applied through the releaser jars from a wash trough. The vacuum is used to draw the solutions through the pipelines from the wash trough, sometimes through the milking machine clusters, being returned to the trough through the releaser jars, being drawn out by the milk pump. In other installations returning solutions are pumped through the milking machine clusters.

Calbert (1953) pointed out that pressure cleaning is neither practical nor as essential on the dairy farm as it is in creameries. Pressure cleaning involves the use of additional cleaning equipment which in a creamery can be used for other purposes. The cost of such equipment in farm installations would not be offset by any economies in labour as readily as with a creamery plant. In many cases the existing pumps, either centrifugal or positive, are used for the circulation of cleaning solutions in a creamery cleaning in place installations.

It must be acknowledged that conditions will differ slightly from one farm installation to another, but the basic cleaning system consists of three or four distinct operations.

Pre-rinse

After milking is completed, the outside of the milking units are flushed with water and brushed to remove any soil and the units fitted into the cleaning circuit. The necessary adjustments are then made to set up the cleaning circuit. Tepid water is then drawn through the system to rinse out the milky residues, and is allowed to run to waste. The advantages of using tepid water have been shown by Patel and Jordan (1964) who investigated the comparative amounts of rinse water at two different temperatures - 39^0 - 50^0F and 110^0F - necessary to rinse pipes of different materials - glass, stainless steel and Tygon (a proprietary type of polyvinyl) tubing - free of residues of different types of dairy soil - skimmed milk, whole milk, ice cream mix and heavy cream. The point at which the rinsing was deemed to be complete was determined by nephelometric means, when the light transmission of the rinse water was the same as fresh water. It was found that the amount of water, either warm or cold, necessary to rinse the residues increased with the total solids content of the soiling product. The amount and condition of the fat is more important than the amount of solids. With cold water, the amount required increased with the fat content, a requirement which was less than with warm (43^{o}C) water. It was shown that with continuous flow rinsing, the ratio of cold water to warm to achieve the same amount of rinsing for a 1½ in. stainless steel pipe was 1:1.13 and 1:1.32 for skimmed and homogenized milk respectively. For 1½ in. glass piping the comparable figures were 1:1.15 and 1:1.40 respectively.

Applying these observations to the cleaning of farm pipelines there would be an additional advantage of rinsing with tepid water, rather than with cold water. At the end of the milking, the pipes would be at the temperature of the milk, and by maintaining this temperature during the rinsing, there would be a reduction in the temperature loss during the rinsing and also the subsequent detergent circulation.

Detergent Wash

The second stage in cleaning consists of the circulation of the detergent solution. A suitable non-foaming detergent, which is compatible with the degree of hardness of the water, is dissolved in water and is circulated through the system. It is normally recommended that the instructions of the manufacturer should be followed in respect of temperature, strength of solution and time of circulation. The amount of the detergent solution in the wash trough must be such that a reserve remains there at all times during the circulation. For reasons of economy in detergent, the minimal quantity may constitute a reserve, but it is suggested that a greater volume of solution in the trough would act as a reserve of heat and so assist in maintaining a higher temperature of the circulating solution. This latter point is also suggested by Scheib (1966a).

It is common practice in the United Kingdom to circulate the sterilant with the detergent. The detergent/steriliser may either be a proprietary compound, in liquid or powder form, or it may be an alkaline circulation cleaner to which has been added the appropriate amount of sodium hypochlorite. If the latter is the case it is essential that it be confirmed that the detergent is compatible with chlorine.

The effect of the addition of the chlorine bearing compound on the cleaning efficiency of the detergent is discussed by the author below.

Walters, Cousins and Edmunds (1949) demonstrated that the bacteriological condition of equipment, sterilised with steam or sodium hypochlorite, was related to the efficiency of the cleaning process.

All equipment which cannot be cleaned satisfactorily in place must be brushed, rinsed and sterilised by hand. In "round-the-shed" installations the stallcock connections require such attention since the cleaning process does not clean all the surfaces in contact with the milk. Also the stallcock fittings incorporate rubber gaskets which present an additional cleansing hazard.

Final Rinse

Following the washing operation, the pipeline system must be thoroughly rinsed in order to remove all residues of the soil, detergents and sterilants. This is necessary under statutory requirements - The Milk and Dairies (General) Regulations 1959. It is only stipulated that this operation be carried out with 'clean' water but it is often recommended in other instructions that this rinse be chlorinated at a rate of 50 p.p.m. available chlorine. This is suggested not only because the bacteriological quality of the water may be suspect, but because the water may be infected from the hose or from the wash trough from which the water is drawn through the plant. The final rinse is often circulated, rather than discharged direct to waste. Where the rinse water is recirculated there is a risk that traces of the circulating detergent will be inadequately flushed from the system and will then dry on to the surface of the pipes. Nokes and Tredennick (1965) reported on an investigation on 33 farms and found that there was a significant difference between the overall figures for final rinses which were circulated and those which were not circulated, and these workers suggested that there is an added advantage in circulating the final rinse for 3-5 minutes. It was found that the concentration of sodium hypochlorite in the final rinse was so variable to be of no significance to the bacterial results recorded, the concentration varying from 0 - 250 p.p.m. available chlorine.

Pre-milking sterilisation

The practice in North America is for the washing and sterilisation processes to be two quite distinct operations (Farm and Industrial Equipment Institute, undated). The plant is washed in the usual manner, rinsed and then the plant is sterilised within one hour before milking since significant bacterial growth could take place between the washing and the next milking. For this reason a 'sterilising' rinse before milking is generally recommended. Such a fourth stage is claimed to improve the hygienic quality of the pipeline. It is often recommended by different manufacturers in the United Kingdom and also by the National Agricultural Advisory Service (1967a) but it is not a common practice probably because, as Widdas (1961) points out, this practice could delay the commencement of milking and so be considered a hindrance by the producers. Middleton, Panes, Widdas and Williams (1965) carried out an investigation on the circulation of a chlorinated rinse for 2 minutes through the system immediately before milking began. The results showed that where the chlorinated solution containing 100 p.p.m. available chlorine was circulated immediately before milking, the total colony count of the pipe-line was lower than when it was circulated immediately after the washing treatment. This applied to both farms in the investigation in spite of the difference in the level of the counts on the two farms. Where the circulation of the chlorinated rinse followed a circulation of a hot detergent sterilizer solution containing 250 p.p.m. available chlorine, the results were not as successful as where the rinse was effected immediately prior to the milking. These improved results, however, were not reflected in improved milk quality. This could be due, however, to the limited scope of the investigation as well as the small number of milk samples taken.

White (1962) recommended that the washing and sterilising treatment be performed as two separate distinct operations since a cleaned surface needs less sterilant, a soiled surface requiring a higher concentration of sterilant in order to penetrate the soil. There can also be a reduction in cost if sterilant use is diminished. On the other hand, a separate treatment would be more expensive in labour requirements. It is also possible that where the two stages are separate, there would be a risk that the sterilising treatment would tend to be shorter in duration than necessary in order to save time. Murray and Foote (1963) obtained satisfactory results over a period of two months on three farms where no sodium hypochlorite was used until the final rinse, when it was used at a concentration of 60 p.p.m. available chlorine.

Thomas (1964) stated that there was little evidence to show an actual increase in the bacterial content of equipment between cleaning and use, but in the course of a few days in warm weather, there is a considerable increase in bacterial content of equipment when the cleaning is unsatisfactory or perfunctory. Cousins and McKinnon (1962), who investigated the efficiency of some chemical sterilants alone and in combination with detergents for the disinfection of farm dairy utensils, found that there was little advantage to be found in applying two separate treatments rather than where they are carried out simultaneously. They pointed out that cleaning would need to be very effective if satisfactory disinfection were to be achieved with a cold rinse lasting only a few seconds. Whilst this is the standard procedure in North America, Snudden, Calbert and Frazier (1961) point out that where cleaning is inadequate, high counts are not uncommon.

Cousins and McKinnon (1962) observe that satisfactory results with the combined detergent/ sterilizer treatment can be obtained even in the presence of milk residues. This claim is only made provided that approved products are used at the recommended concentration for the correct time on equipment which is in good physical condition.

Their conclusions were based on bacteriological results obtained by the Hoy Can Test (Cousins, Hoy and Clegg, 1960), a method of testing which has been criticised by Johns (1962) and Walters (1964).

Johns (1962) feels that too much attention has been given to the sterilising aspect and not enough on the cleaning. It is stated that the concentration of available chlorine (250 - 300 p.p.m.) is unnecessarily high, and a concentration of 50 p.p.m. is suggested. Johns describes an investigation where the use of iodophors was compared with a control procedure using a chlorinated alkaline detergent. The iodophor was used for washing the equipment (25 p.p.m. available iodine) with a pre-milking rinse of a half strength iodophor solution (13 p.p.m. available iodine). The control technique was the washing of the equipment in a chlorinated detergent (55 p.p.m. available chlorine) and a pre-milking rinse of a hypochlorite solution (100 p.p.m. available chlorine). The bacteriological results were as good for the iodophor as for the hypochlorite although the concentration was only ⅛th of that of the hypochlorite. Johns points out that these results support the view that with adequate cleaning, strong concentrations of a bactericide are unnecessary. The recommendation of such high concentrations implies that they are used to cover up poor cleaning techniques. It is emphasised that these results were obtained by producers who received a minimum of supervision during the trials and did not revert to the weekly heat treatment or periodic descaling recommended by many British workers, (Cuthbert, 1961; Clegg, 1955; and Edgell, Lomax, Adams and Aitken, 1958) which are necessary to obtain satisfactory results with chemical sterilisation. Since the equipment of each producer was descaled before the investigation began, and also since the iodophor used during half the investigation was acidic, it is not surprising that it was found unnecessary to have recourse to descaling. Also, the renewal of the milking liners which was made before the testing began would have assisted in maintaining a reasonable hygienic standard during the period of the investigation.

The results show that iodophors exhibit cleaning and sterilising properties which are comparable to, and, on a concentration basis, superiod than a chlorinated detergent. Johns' criticisms however, do appear to be justified in that attention is paid in official publications to the necessity of additional treatments for the removal of residues such as milkstone, or other residues (Ministry of Agriculture, Fisheries and Food, 1959), Edinburgh and East of Scotland College of Agriculture (undated) and West of Scotland Agricultural College, 1964). The presence of such residues are indicative of unsatisfactory cleaning techniques and in many cases could be avoided by correct selection of detergents by the application of correct cleaning techniques.

Johns (1962) reported that Edgell and Widdas (1962) studied two different makes of machines which had been specially designed for circulation cleaning. It was found that there were milk residues on rubber gaskets, connections and joints after six months. It was found that supplementary heat treatment and periodic dismantling were necessary to keep the bacterial counts at a satisfactory level. Johns (1962) states that North American experience indicated that pipeline installations are capable of being cleaned in place without the necessity of recourse to heat sterilisation. This fact is generally appreciated by workers in the United Kingdom, and Clough (1964) points out that, since the existing connections are relatively inexpensive, it is unlikely that joints and crevices will be eliminated. Clough suggested that effort should be directed towards the efficiency and economy of hot water sterilisation rather than attempting to re-design the equipment to make chemical sterilisation more effective by ensuring contact by the solution with any residual bacteria. The system of hot water sterilisation developed for parlour installations (Clough, Akam and Cant, 1965) could be adapted for round-the-shed systems but it would present additional problems, however, amongst which are the suitability of the stall cock fittings and the volume of hot water required.

It was found by Clegg and Hoy (1955) that if the cleaning and sterilising treatment in the morning is thorough, a disinfecting rinse alone is all that is necessary in the evening to ensure an equally satisfactory keeping quality from both morning and evening milk. To provide a margin of safety the concentration of sodium hypochlorite rinse is double that of the rinse after the morning rinse - about 125 p.p.m. available chlorine instead of 60 p.p.m. The development of this rinse is interesting. It was first recommended in 1943 at a concentration of 10 p.p.m. available chlorine, being merely sufficient to sterilise the rinse water. Later it was considered better to make this an active sterilising rinse in order to continue the sterilising effect of the preceding detergent steriliser wash. With the introduction of the chemical rinse alone in the evening the concentration of the hypochlorite in the evening rinse was doubled (Ministry of Agriculture, Fisheries and Food, 1954).

Whilst it must be admitted that this treatment alone, which lasts only a few seconds, would not constitute effective treatment, morning milk of a satisfactory bacteriological quality can be produced but only when there is a satisfactory full detergent/steriliser treatment once a day after the morning treatment.

Nokes and Tredinnick (1966) in their investigation on circulation cleaning under normal farm conditions found that one of the factors giving the best results for plant and clusters was that of the application of full cleaning treatment twice daily. It was found that with sterile rinses drawn through the plant 22% were satisfactory when the full cleaning routine was applied twice daily, compared with only 13.3% where it only applied once daily.

Automatic control

The control of the washing and sterilising operations can be operated by an automatic device operated by the pulsation system of the milking equipment. The plant is firstly rinsed adequately by the operator when the sequence timer will control all other operations, finally switching off the vacuum producer. The pulsations operate a diaphragm relay which turns a ratchet wheel. The rotation of the ratchet wheel, through a worm and pinion, moves a valve which switches the vacuum either to the wash trough or to the rinse tank valve.

The timer control knob, when set to 'wash' starts the circulation of the detergent which continues for 17 minutes. This is followed by a three minute drain period when the detergent solution is drained away. A rinse solution is then automatically transferred to the wash trough and circulated for 10 minutes. This is followed by a three minute drain period when the vacuum producer is switched off.

The installation of this system not only permits the full cleaning treatment to be effected after each milking, it also permits a timed sequence of operations to be carried out in the absence of any operator.

Hot water requirements

Faults often occur in pipeline installation cleaning by insufficient attention being given to the volume of water needed for the cleaning solution. Actual measurements of the water being circulated often show that the gallonage is either much less or much more than that which was assumed. Where the detergent concentration is too high it may be manifested in two ways, either by foaming of the detergent, or by corrosion, both of which are to be avoided. Where the detergent concentration is inadequate, it results in a lowered cleaning efficiency and ultimately it may reach a concentration where it cannot be adequately or economically compensated by either adjusting the temperature or the time of circulation.

The correct operation of a cleaning system demands an adequate supply of hot water. With the majority of pipeline installations where chemical sterilisation only is practiced the traditional method of raising steam on the farm, the wood or coal-fired boiler is often dispensed with, the hot water being provided by electrical water heaters. The largest demand for hot water is that for cleaning equipment after morning milking and this would necessitate a large volume of water being used in a relatively short time. Since it is not practicable for the heater to heat additional water once the initial demand is made, all the hot water must be available at the beginning of the cleaning operation.

Turner (1964) states that a 30-gallon electric heated can heat about 6 gallons per hour, whilst those with a top and bottom heating element, connected to a fast heating circuit have a recovery rate of about 35 gallons per hour, but, of course, these figures could be changed by an alteration in the electrical loading.

An indication is given (Electrical Development Association, 1956) of the minimum electrical loading required by water heaters in order to ensure that there will be sufficient hot water for the afternoon washing as well as that required for the morning wash. With an electrical loading of 3kW and a heater exhibiting 85% efficiency, 61 gallons of water at 38°C could be recovered in 7 hours.

Kline and Fox (1966) report work by Church (1954) who showed that larger heaters are more efficient in heating and storing water than smaller heaters. The amount of water which can be supplied by a heater without a significant drop in the temperature depends on the size of the tank and the draw-off rate. The total usable quantity of water was shown to vary from 55% of the storage capacity for a 20 gallon heater to 89.5% of tank capacity for an 80 gallon unit.

Kline and Fox (1966) indicated that the following would be the desirable sizes of water heaters for farm dairies:-

30 gallon heater for herds where hand cleaning methods are used.

50 gallon heater for automatic cleaning and/or pipeline installation.

80 gallon heater for large operations with over 50 milking cows and/or pipeline over 100 feet long.

The observation is made by Kline and Fox that there are two possibilities for providing the water at the required temperature. The first is by the operation of a large water heater at the lowest acceptable temperature whilst the second is the provision of two or more smaller heaters maintained at higher than the required temperature. The first method will be more expensive initially but will be more economical to operate, whilst the second will be less expensive initially but will cost more to operate because of greater heat losses from the tanks. This suggestion is also made by the Electrical Development Association (1965).

The relationship between the storage and use temperature of hot water and the daily electricity consumption is given in a publication which covers, *inter alia*, aspects of the use of electricity for steam raising and water heating (Electrical Development Association, 1965). An approximate indication is given of the daily consumption of kWh for storing 10 gallons of water in a well-insulated container at different temperatures.

Storage and use temperature		Approximate consumption of electricity for using and storage of 10 gallons water
°F	°C	kWh
100	38	2.0
120	49	2.5
140	60	3.3
160	71	4.1
180	82	5.0
200	93	7.5 (Electrical Development Association 1965).

Nokes and Tredinnick (1965) noted that one factor which could have a considerable effect on the result was whether two separate sources of hot water was available. Only one of those should be used for circulation cleaning, the second being used for udder washing water, calf feeding etc. A similar observation is made by Scheib (1966a) who pointed out that a variation in water temperature can be due to abnormal conditions which may have necessitated the use of more hot water than usual. Since the cleaning of the pipeline is the last operation in cleaning, smaller amounts of hot water would thus be available due to the slow recovery rates of electric immersion heaters.

Supplementary cleaning operations

In order to maintain a satisfactory standard of hygiene it is generally recommended that particular attention be paid to specific sections of the installation.

Milking units should be dismantled weekly and thoroughly cleaned by brushing out. The liners should be regularly defatted by immersing in a proprietary defatting solution or in a 3% solution of caustic soda to which is added 0.25% of a sodium salt of ethylenediamine tetra-acetic acid, the latter constituent being essential in hard water areas. Such a treatment extends the working life of the liners and adds to their efficient operation. Liners which have not been defatted can show an increase in weight, due to absorbed fat, of more than 12% and in such a condition it is practically impossible to make them bacteriologically acceptable.

After immersion in the caustic solution for six to seven days the liners should be thoroughly brushed out with a detergent/steriliser solution to remove the fat leached from the rubber.

American practice suggests that this rinsing be carried out by a concentrated organic acid solution (University of California, 1964). In this way all residual caustic and the accompanying soil are thus easily and completely removed, leaving the rubber parts in a completely clean and neutral state ready to be placed back in service.

McFetridge (1962) found that brushing the inside of liners damaged the surface of the rubber and created conditions favourable to bacteria. Whilst these rubber fittings are often the only ones which receive attention, all other rubber fittings should be subjected to similar treatment. This is suggested by McCulloch (1965) who stated that gaskets and short and long rubber tubes can show increase of 2-4 or even 5 per cent in weight. Whilst the rubber equipment is being defatted, the fittings can also be examined for worn, softened or perished parts or for residual deposits.

Maxcy (1966) estimated the soil resudues in pipeline systems by the rate at which chlorine was dissipated when a chlorine solution was kept in contact with the cleaned surface for a period of several hours. It was shown that the soil was not uniformly dispersed throughout the pipeline system, but was concentrated in certain localised areas where micro-organisms would be able to obtain adequate nutriment for proliferation. These areas were the joints and also pump seals and other dismountable fittings. It was suggested that design characteristics are important and should be tried out under practical conditions before being introduced into commercial installations. Previous work by Maxcy and Shahani, (1961) had shown that were sufficient soil to support bacterial growth uniformly spread throughoth the system, it should be capable of being shown by chemical means.

As well as the rubber fittings, the main vacuum line, including the sanitary trap, should be cleaned weekly or when milk has entered the vacuum line. A contaminated vacuum line can provide a source of infection and can contribute materially to poor quality milk. This is cleaned by drawing hot detergent solution through the system, ensuring that the volume of detergent is less than that of the sanitary trap. It is suggested (University of California, 1964) that a small volume of detergent be drawn through each stall cock, commencing at the one nearest the vacuum pump. This would irrigate each stall cock more effectively than would be the case were the detergent solution drawn from the most distant stall cock, as is the usual recommendation, (West of Scotland Agricultural College, 1964). Once the sanitary trap has been emptied, the procedure is repeated with clean fresh water.

McCulloch (1965) suggests that in very hard water areas, it is advisable to prevent scale build up by circulating a milkstone descalent at a quarter of the normal strength. Whilst it can be given at less frequent intervals it should not be done more frequently than once per month. It is pointed out that, in the earlier stages of build-up, milkstone would not be visible, but once this stage has been reached, further development is much more rapid. A similar recommendation is made by Edinburgh and East of Scotland College of Agriculture (Advisory Leaflet 47) but the West of Scotland Agricultural College (1964) points out that acid descaling is not recommended for regular use, the presence of milkstone indicating faulty cleaning methods. The regular circulation of an acid descalant is, however, generally recommended in North America (University of California, 1964). Kosikowski and Holland (1958) state that, dependent on the characteristics of the water supply, it may be found necessary to substitute an acid descalant for the alkaline solution once or twice a week. This practice is the basis of the Ruakura system of cleaning milking equipment (McFetridge, 1962). In New Zealand and Australia the general practice is for the pipeline to be rinsed with cold water containing 0.03% non ionic wetting agent and the pipeline is then washed with hot alkaline detergent, rinsing with hot water. Immediately before the next milking it is sterilised with an iodophor solution - 25 p.p.m. available iodine. Johns (1967) reports that this system has been suggested by Whittlestone and confirmed that its use results in much less milkstone formation and less corrosion than with the previous use of an alkaline cleaner and sodium hypochlorite.

Conclusions

The development of the "round-the-shed" pipeline system of milking has developed from the extended milk lift and offers a simple method of conveying the milk from the clusters direct to the cooler. Whilst economically such a system is more expensive to operate than a parlour, it does permit the continued use of the byre as well as not necessitating a change in farming practice. The installation however, does require that close attention be paid to the direction and magnitude of the fall of the pipeline which must permit thorough draining not only of the milk but also the cleaning solutions. The installation does contribute more to the efficiency of cleaning than appears to be appreciated.

The cleaning of pipeline installations can be effected to the required hygienic standard by circulation cleaning using a suitable detergent at a suitable temperature, provided that the vacuum pump is able to provide sufficient turbulence in the circulating solution.

The use of rubber connecting sleeves, and rubber stall cocks does provide a hazard in cleaning and such items must receive additional treatment to remove all residues and also be regularly replaced when necessary.

Additional treatment such as the circulation of acid descalant and cleaning of the vacuum line should be carried out regularly.

Emphasis must be placed on the importance of cleaning the pipeline and all other fittings in order to achieve the necessary standard of hygiene. Reliance is often placed on the sterilant to compensate for any inadequacies in cleaning. Whilst this may be the case where steam or boiling water was used for sterilising, where chemical sterilisation is practised, the cleanliness of the plant is of greater importance.

EVALUATION OF THE EFFICIENCY OF CLEANING COMPOUNDS

The evaluation of cleaning processes is limited by the difficulty of determining the degree of soil removal and also by the poor reproducibility of any testing system. Many workers have used different methods based on visual inspection or bacteriological, colorimetric, photoelectric and radioactive tracer techniques, each method possessing specific advantages and disadvantages. Visual examination is clearly unreliable for quantitative estimates and modifications to this technique, involving the incorporation of dyes or fluorescent materials have not proved satisfactory. In practice however, cleanliness is frequently judged by visual appearance. The value of apparent visual cleanliness is based on the assumption that, while a pipeline may contain a sterile soil and not affect the quality of the milk passing through it, it is preferable that no soil be present to serve as a possible harbour for bacteria.

There have been many attempts by different workers to develop systems of detergent evaluation which were sensitive and at the same time reproducible, so permitting the comparable evaluation of compounds of different formulations.

Many different factors contributing to the efficiency of the detergent may be measured accurately under laboratory conditions, and so provide valuable supplementary information in detergent testing. The more generally investigated performance tests would include the measurement of pH or alkaline titration; water softening powers; solvent action; surface tension depressant; emulsification and rinsability.

A final assessment of the detergent cannot be made accurately in a laboratory and it is impossible to predict its efficiency on the basis of the results of the above tests alone, nor can it be assumed that its performance is the mean of these properties. In addition, there are other factors which affect the practical effectiveness of the detergent, such as time of application, temperature of solution, water hardness and whether the constituents exhibit synergism These factors are infinitely variable under practical conditions, so that, even when one or more of these factors is standardised, any laboratory findings cannot be related to the efficiency of the detergent at the farm. The only completely satisfactory way of assessing the efficiency of the detergent is to try it out under existing conditions at the farm itself over a period of time. Even then, such results would only be really applicable at that particular farm.

Under laboratory conditions, any method by which the quantity of residual soiling material can be measured may be applied to determine the comparative detergent efficiency. Purely laboratory methods have involved the soiling by milk, or other standard soiling mixture, of glass or metal slides and then subjecting the slides to detergent cleaning under controlled conditions. The resultant cleaned slide may then be examined in one of several ways and the amount of residual soil used as a basis for comparison.

Laboratory methods fall into the following categories: which depend on the system adopted to measure the residual soil.

Photoelectric: With this system, the optical density of a soiled glass slide is measured before and after cleaning. This method was used by Gilcreas and O'Brien (1941); Johns (1946); Morgan and Lankler (1942); Mead and Pacess (1962) and Garvie and Clark (1955).

Mann and Ruchhoft (1946) remarked when discussing the evaluation of detergents for dishwashing that, since the human eye is not sensitive within fine limits to grade the amount of soil, it is necessary to employ photoelectric means. In addition, the use of such equipment permits the determination to be awarded a quantitative value, which thus allows comparisons to be made between different detergent compounds. Similar methods were used for the same purpose by Walters (1948) and Hucker (1942). Hughes and Bernstein (1945) designed an instrument for this purpose since they had found that equipment which was commercially available for the measurement of light films on washed glass slides were unsuitable for this purpose. They claimed that the usual method of photoelectric comparisons suffer from the difficulty of making measurements by difference - i.e. between a washed slide and a cleaned slide - when the difference was small. The maximum relative error involved in the measurement of density of films by this method is equal to the sum of the absolute error in the two primary measurements divided by the differences between the two primary methods. In practice this method becomes unreliable for the measurement of values below 1% decrease in light transmission. In order to overcome this defect, Hughes and Bernstein made measurements of the proportion of the incident light scattered by the soiled surfaces and they described the apparatus constructed to perform this function.

Fouts and Freeman (1947) described an apparatus which they called the Deterg-o-meter which permitted soiled glass slides to be cleaned in a detergent solution under standard conditions and which were then rubbed against a sponge rubber brush.

Chemical: Mohr and Junger (1953) tested detergents for their cleaning efficiency and corrosive properties by using them to wash milk cans in an automatically controlled system and then examining the interior for protein residues by nitrogen determination.

Maxcy and Shahani (1960) correlated the turbidity of used detergent solutions of a circulation cleaning system by the nitrogen content, measured by a Kjeldahl analysis. The method was shown to have a sensitivity of 2 p.p.m. milk solids.

Maxcy (1966) estimated soil residues in pipeline systems by the rate of the chlorine dissipation. The system was flooded with a chlorinated solution and the quantity of residual soil determined by measuring the reduction in soil content.

Radio-active techniques: These methods are based on the measurement of the radioactivity of the soil both before and after the cleaning process. Sieberling and Harper (1956) considered that radio-active tracer techniques offered greater sensitivity and better methods. Two disadvantages of this method are the cost of the equipment and the potential hazard to the operator.

With radioactive tracer techniques the soil may be labelled with a radioactive tracer, or, alternatively, the bacteria may be so labelled. Several workers have discussed the different methods of adding the labelled constituent to the soil. Tracers may be added as the inorganic salt to the milk which is used as the soil, or it may be added *in vivo*. Jennings, McKillop and Luick (1957) using P_{32} labelled milks, compared *in vivo* and *in vitro* labelled milks, since it was felt that, by adding it as an inorganic salt, any results would tend to be an index of the removal of inorganic residues only. They reported that there appeared to be no difference as a result of the method of addition.

On the other hand, Peters and Calbert (1960) compared the rate of soil removal as a function of the removal of radioactivity of *in vivo* labelled milk, *in vitro* labelled milk and milk containing P_{32} labelled bacteria. It was concluded that correlation was best for the labelled bacteria, soil being removed very much faster than radioactivity in the *in vivo* labelled milk and much faster for the *in vitro* labelled milks. Jennings (1961) confirmed his previous findings and suggested that these discrepancies were due to differences in milk film used by other workers.

The radioactive tracer used has also varied. Radioactive phosphorus P_{32} is the most usual material and this has been used by Jennings et al (1957); Jennings (1960, 1961); Pflug, Hedrick, Kaufmann, Keppeler and Phiel, (1961); Cucci, (1954); Hays, Burroughs and Johns, (1958). Masurovsky and Jordan (1958, 1960) used P_{32} labelled bacteria, as did Peters and Calbert (1960).

Sieberling and Harper (1956) used P_{32} but stated that it was unsatisfactory since it reacted irreversibly with stainless steel and suggested that Co_{54} was better in that it yielded more reliable results. Jennings (1963) stated that, based on his findings and results obtained by Hensley, Long and Willard (1949) and Hensley (1951) it was probable that this was due to an adsorption phenomenon.

The material which has been labelled with radioactive tracers has also varied with different workers. Anderson, Satonck and Harris (1959, 1960) and Bourne and Jennings (1961) used C_{14} labelled tristearin, whilst Harris and Satanek (1961a) used C_{14} labelled stearic acid, tristearin, triolein and algal protein soils. Bourne and Jennings (1961) used C_{14} labelled sucrose in detergency studies.

Cucci (1954) in a study to determine the amount of milkstone deposited on rubber, Pyrex glass and Tygon - a plastic material - used homogenised milk to which P_{32} in the form of a phosphate had been added.

Anderson et al (1959) used tristearin which had been labelled with C_{14} in the study of the removal of fatty soils from glass surfaces, and a similar tracer was used by Harris and Satanek (1961b), Jennings et al (1957) and Jennings (1960, 1959a, b) used a dried film of P_{32} labelled homogenised milk as the standard soil.

Other workers have used radioactive labelled bacteria which have been incorporated into the soil as a means of estimating the residual soil. Peters and Calbert (1960) incorporated P_{32} into bacterial cells prior to their addition to the soil. Such a method resulted in a linear relationship between the removal of the test soil and of radioactivity. No such agreement was found when the P_{32} was added directly into the milk or the test soil, whilst more radioactivity than soil was removed when the phosphorus was introduced *in vivo.*

Bacteriological: By far the greatest amount of published work refers to simple bacteriological methods for determining the efficiency of cleaning although Holland, Shaul, Thickes and Windle (1953) showed that there was no direct relationship between the removal of the bacteria and of soil. However, the bacteria constitute that section of the soil which it is essential to remove under practical conditions. Unless the amount of residual soil is very great it will have comparatively little effect on the quality of the milk passing over it, which is not the case with bacteriological contamination. Probably the most important contribution is that of Neave and Hoy (1947) who investigated the effectiveness of the different compounds by endeavouring to simulate usage conditions using tinned trays which had been soiled by test organisms. Later, Hoy and Clegg (1953) described a basic practical comparison by using soiled milk cans. This is the test which is used as the basis for the official approval of all the sterilants and detergent/sterilants in the United Kingdom.

The Hoy Can Test has received adverse criticism from several quarters. Walters (1964) observed that it was not applicable to compounds which have been formulated for cleaning and sterilising by circulation methods. However, the alternatives offered by Walters which were those used for regulatory purposes in the United States, appear to be purely laboratory methods, and as such, would appear to offer less than the Hoy Can Test.

A similar test developed by Lisboa (1959) used, as the test surface, a piece of stainless steel tube of the type which is in general use in farm byre installations. Such a method gives results which are comparable to those obtained by the Hoy Can Test and requires less extensive testing facilities necessary with the approved method.

Any bacteriological results obtained either by rinse or swab techniques indicate at best, the number of viable bacteria on the surface and give no indication as to the physical cleanliness of the equipment nor the type of the growth potential of the bacteria present.

CLEANABILITY

If a surface is perfectly clean it follows that it will be quite free from all kinds of residues whether organic or inorganic.

The ease with which a surface can be cleaned depends on the material of construction, the finish of the surface and the design of the equipment. In this context 'cleanability' refers to the ability of a surface or material to be cleaned - that is, rendered free from all adhering soil - whereas 'cleansability' refers to its ability, not only to be rendered physically clean but also free from all viable organisms.

The relative cleanability of milk contacting surfaces made of different materials has been investigated by several workers who assessed the comparative ease with which different surfaces could be cleaned by the estimation of the viable organisms present after the surfaces have been cleansed. As is pointed out by Masurovsky and Jordan (1958) such evaluations, whilst useful as field tests and techniques, proved to be inadequate when applied to a quantitative estimation of the relative cleanability of materials exhibiting different surface finishes.

Other workers, concerned with the cleanability of materials used for dishes, have tried to evaluate the materials and finishes by the determination of the soil retention capacity of the surface. Photometric techniques, used by Mallman, Zackowski and Mehler (1947) and fluorescent dyes (Domingo 1950) have been found to be lacking in sensitivity at low levels of residual soil. Radio-isotope techniques are suggested by Masurovsky and Jordan (1958) as means of measuring the cleanability of different finishes and materials with a method which permits an accurate and reproducible comparison to be made. Not only can the quantity of soil be determined but also the pattern of soil distribution be demonstrated.

Such a system was used by Ridenour and Armbruster (1953) who investigated the bacterial cleanability of different types of eating surfaces. The evaluation was made by using a test organism incorporated with a radioactive tracer - P_{32}. The removal of the soil from the surface, calculated by measurement of the radioactivity, permitted a comparative evaluation to be made of different surfaces - glass, china, stainless steel, plastics and aluminium. Glass, china and stainless steel were the easiest to clean, between 97% and 99% of the test organism being removed. If, however, the surfaces of the test plates were damaged either by wear or scratching, the efficiency of soil removal was depressed but again the same comparative efficiency was found.

Kaufmann, Hedrick, Pflug, Phiel and Keppeler (1960a) compared the relative cleanability of four different finishes of stainless steel after soiling with milk solids. By the inoculation with spores, and measuring the degree of removal by bacteriological techniques, it was found that there was no significant difference in bacterial cleanability between these four finishes.

Holland, Shaul, Thickas and Windlaw (1953) studied the cleaning in place of stainless steel pipelines and the suitability of different detergents and sterilisers. They found that there was no correlation between film deposits and bacterial counts, some of the lowest bacterial counts occurring where a heavy film was apparent.

Hays, Burroughs and Johns (1958) investigated the removal of dried dairy soil, contaminated with *Escherichia coli* from the surface of six different finishes of 18:8 stainless steels as well as from 3 suitable moulded plastics. The standard finish of stainless steel was 120 grit and the results were compared, both by using bacteriological and radioactive techniques, the *E. coli* being grown in a broth containing radioactive phosphorus.

The test materials were cleaned with four different cleaning compounds at room temperature and the results showed that in all cases the contaminating soil was completely removed, from which it was concluded that the several finishes of stainless steel were cleaned as readily as the standard 120 grit, after manual scrubbing for 15 seconds at room temperature.

Fortney, Baker and Bird (1955) who made a study of the cleaning in place of stainless steel lines, noted that there appeared to be no difference in cleaning efficiency with pipelines having different finishes. With glass and stainless steel lines, the bacteriological condition indicated that there was no significant difference.

Davis (1963) used bacteriological techniques to investigate the cleansability of different materials such as glass, stainless steel, plastics, aluminium, ceramic, painted surfaces and teak. It was found that of the materials examined, stainless steel and vitreous enamel were approximately equal to glass. Abrasion made to similate wear, did not appear to affect cleansability. Plastics appeared to give anomalous results which were ascribed to the bacteriostatic effect of some chemical substances contained in the plastics. Masurovsky and Jordan (1958) discussed the relative cleansability of some plastic materials which they examined in their investigations on the cleansability of milk contacting surfaces using bacteria labelled with P_{32}. It was shown that plastic materials which possessed a smooth moulded surface were generally quite easily cleaned. Certain formulations which were not so readily wettable with aqueous solutions were more difficult to clean than their more readily wettable counterparts. Some plastics, which at first glance appeared to have a readily cleansable smooth surface had, in reality, small imperfections in the form of small pits or pinholes distributed over them. It was suggested that this accounted for the greater soil retention of these samples of polyvinyl chloride and polystyrene.

Those compounds which possessed a spongy or porous surface proved to be difficult to clean, and there were variations between different specimens of the same material. Polyester fibreglass laminate, whilst not possessing a porous surface, had a brittle, jagged surface criss-crossed with fibreglass strands. One specimen retained about three times as much soil as another specimen, and this was ascribed to the presence of cavities between the fibreglass strands and the brittle polyester resins. Upon abrading this type of surface, a quite porous sub-surface was exposed which proved to be most difficult to clean. It should be pointed out, however, that where equipment fabricated from fibreglass is cleaned only by circulating cleaning techniques, the inner milk-contacting surface would not suffer any mechanical damage and its cleansability would remain uniform throughout its working life. In general, abraded plastic specimens exhibited about five times the soil retention of the same materials before any abrasion had occurred. It was shown that stainless steel and glass as well as the plastic materials were adversely affected by abrasion - the materials under investigation were abraded by light rubbing with No.1/2 Emery cloth for 10 minutes. Abrasion of the surface not only affected the ease with which they were cleansed but also affected the order of cleansability. This is not in agreement with Davis (1963) who found that abrasion did not appear to affect the order of comparative cleanseability. The difference in findings can probably be explained by the fact that Masurovsky and Jordan (1958) used radioactive techniques whereas Davis (1963) used conventional bacteriological methods. It was pointed out by the former workers that the count of radio-activity due to the bacteria left after the cleaning was used in the statistical analysis rather than the percentage of organisms removed during the cleaning. This permitted much finer distinctions to be observed in the relative effectiveness of the cleansing operations.

Kaufmann, Hedrick, Pflug and Phiel (1960b) examined the relative cleansability of various finishes of stainless steel which had been incorporated into a refrigerated form milk tank. No significant difference was found in the relative cleansability of the four different finishes which were examined, the evaluation being effected by bacteriological examination of both a standard swab test, conforming with the standard methods described by the American Public Health Association, (1953), and a large swab test based on a 120 inch area (the standard swab was based on swabbing an area of 40 sq. in.). With regard to the removal of bacteria, all four finishes were found to be cleansed equally well. These results were in agreement with previous work (Kaufmann <u>et al</u>, 1960a) where the relative cleansability of different finishes were compared using a laboratory spray washing device. The end panels of the test tank were not brushed with detergent and this permitted a visual observation of the build up of residual soil. A film which was produced after 12 consecutive soilings, when the cleaning operation was limited to rinsing and sterilisation, was demonstrated by treating a strip with a slurry of chlorinated alkaline cleaner. The film was not readily detected prior to the treatment with the detergent. There was no significant difference in the bacterial count on the finishes incorporated in the end walls of the tank in spite of the soil build up. It was stated by the authors that in the cleansing of a stainless steel surface, once it has been covered by a layer of soil, the original surface can no longer effect the rate of build up which, under identical conditions, should be equal for all dirty surfaces, irrespective of the original surface finish.

Against this wealth of information which appears to show that the cleanability of stainless steel surfaces is not affected by the surface finish, a study of the relative cleanability of milk contacting surfaces by Masurovsky and Jordan (1958) showed that the surfaces which displayed the greatest ease of cleanability were the highly polished, non-porous surfaces. The evaluation was made by measuring the removal of bacteria which had been labelled with radio-active Phosphorus $_{32}$ and which were incorporated in different test soils, upon different milk-contacting surfaces.

It was found that numerous consecutive soiling and washing treatments of a surface resulted in a general increase in the number of bacteria retained by the surface. In addition, although brushing removed bacteria from smooth surfaces, it was less effective for abraded or porous surfaces.

The result of all the tests performed showed that the order of relative cleansability was, firstly, highly polished and non-porous surfaces; secondly, finely ground and smoothly moulded surfaces, and the cold rolled, abraded, blasted and porous finishes were the most difficult to clean.

These conclusions are in agreement with those of Futschik (1958) who compared the cleansability of three different grades of stainless steel, which had been soiled experimentally with raw milk, or cream or starter, and tested by determining the counts of residual bacteria.

Whilst these two opposite results appear to be irreconcilable, Jennings (1961) in a review article on the scientific and technical aspects of circulation cleaning, reported an interesting aspect of detergency concerning the energy relationships in detergency which had been offered as a possible explanation to account for this apparent disagreement.

Harris, Anderson and Satanek (1961) discussed the concept of adsorption and desorption as affected by both the polarity of the adsorbed surface and that of the solid substance. Investigations made by them were interpreted as supporting this theory, illustrating differences between the adsorption tendencies of the different test soils - algal protein, stearic acid and tristearin. Working with glass, quartz, steel and aluminium they postulated that these substances adsorbed anionic and non-ionic surface active agents as well as different sequestering and chelating compounds. Such adsorbed materials affected the degree of soil applied subsequently. Pre-treatment of a surface of a soil with alkali generally increased its adsorptive powers more than an acid treatment. Jennings quotes Hensley, Long and Willard (1949) and Harker (1959) whose work appeared to support the conclusions of Harris et al.

In later work, Harris and Satanck (1961b) found that freshly ground glass exhibited more adsorptive sites than stainless steel per unit area, although the sites were less tenacious. They calculated that the roughening had increased the surface area approximately twice. This suggested that the greater soil retention of a roughened surface may not be entirely due to entrapment of soil in voids and crevices, but at least in part to a physical extension of the surface so that a greater area is exposed.

Anderson, Satanck and Harris (1960) studied the removal of stearic acid from frosted glass by carbon tetrachloride. They found that the soil is, to a degree, readily removed. Once a certain stage is attained, however, further removal becomes extremely difficult, and a relatively stable and tenacious film remains on the surface. Anderson and his co-workers suggested that this tenacious residue was a monomolecular layer, probably held by forces of adhesion. Bourne and Jennings (1963) in their kinetic studies of detergency, showed that this residual layer was thicker than a monomolecular layer since in their investigations, using tristearin as the soil and 0.3N NaOH as the detergent and stainless steel as the surface, this layer was approximately three molecular thicknesses, even when allowing for the rugosity of the test strips. Bourne and Jennings present the concept of two distinct soil species and this is supported by work previously completed by other workers. Hucker, Emory and Winkel (1951) and Masurovsky and Jordan (1960) have reported that one of the problems in practical detergency is the inability to remove completely all residual soil, and there is a gradual accumulation of a residual soil layer with repeated soilings and washings. With the increased build up of the soil layer would be an increase in the residual bacterial population which would be able to secure cover in the deposition of subsequent layers of milk solids.

Jennings (1961) points out that this data is of significant practical importance, since, if methods could be found to satisfy the adsorptive sites of surfaces with materials that would not bind milk solids, such as certain silicone preparations, better cleaning could be achieved with a smaller energy requirement.

In the absence of such methods, however, the cleaning operation must be so designed to remove such residual layers and this is generally effected by the application of an acid treatment.

In order to maintain a satisfactory hygienic state of the equipment, therefore, it is necessary that the milk contacting surfaces be as perfect as possible, in order to limit the deposition of any soil or any residual bacterial infection. The use of stainless steel of a suitable quality and finish or of boro-silicate glass does assist in presenting a smooth unbroken surface which will successfully and continuously be unaffected by any process. The use of plated accessories in milking equipment should be avoided and any such equipment be replaced. The greatest cleaning hazard insofar as surface is concerned, is that presented by rubber sleeves and stallcocks which are difficult not only to clean, but also sterilise. In order to removal all milk residues and residual bacteria such fittings must receive regular and thorough cleansing treatments such as defatting or immersion cleaning. Fittings of a more satisfactory and possibly more sophisticated design would be difficult to justify economically. Existing types of fittings in view of their limitations must receive this additional attention to their cleansing in order to permit the production of milk of a satisfactory quality.

BACTERIOLOGICAL EXAMINATION OF CLEANSED PIPELINES

The determination of cleaning efficiency using bacteriological methods was, for many years, based on the bacteriological examination of the first milk in contact with the cleaned equipment surfaces. However, since the majority of the problems were found to be due to faulty cleaning and sterilising techniques, such a method was but an indirect system. A more direct approach therefore would be by a bacteriological examination of the cleaned equipment in order to determine its hygienic conditions. For this purpose, rinses and swabs are extensively used.

The earliest reference to such a system of examination is that of Mattick (1921) who reported the use of sterile saline rinses, swab rinses and swabs in the bacteriological examination of milk cans and other equipment.

Cousins (1963) noted that where sterilisation has been effected by chemicals it is essential to add an inactivator to the rinse in order to render ineffective any residual bactericide. It was reported that 6 hours after a small 2-unit machine had been rinsed with a solution containing 150 p.p.m. available chlorine a rinse of sterile water passed through the unit contained 4 p.p.m. available chlorine. Similarly, five minutes after a pre-milking rinse of 50 p.p.m. available chlorine had been applied, a sterile water rinse of the equipment contained 17 p.p.m. chlorine. Normally rinse solutions contain 0.05% sodium thiosulphate ($Na_2S_2O_3$)(w/v) and this concentration would be sufficient to inactivate 10 times this concentration of residual chlorine.

Cousins (1963) pointed out that in larger plants, and especially where drainage is incomplete, this amount of thiosulphate would not be sufficient and it is then advisable to check the rinse for any residual chlorine.

Similarly, where acids or alkalies are used to sterilise equipment, it is necessary for a sterile phosphate buffer to be added to the sterile rinse before use. If the pH of the rinse after use is not within the pH range of 6.8 - 7.2 further addition should be made. Di-potassium hydrogen orthophosphate

(K_2HPO_4) is used for neutralising acid residues and potassium hypophosphite (KH_2PO_4) is suitable for alkaline residues.

With a sterile rinse, to which has been added a suitable inhibitor, the method of sampling, however, as indeed with any sampling technique, it is imperative that a standard method be used in order to permit comparisons to be drawn between different results. Such a standard system was first drawn up by the National Agricultural Advisory Service in 1942 for England and Wales (National Agricultural Advisory Service, 1942). This method did not, however, make any allowance for the different surface areas of the equipment examined and it did not therefore permit any results to be compared with any desired standard. It was also found by Thomas, Ellison, Griffiths, Jenkins and Morgan (1950) that were the colony counts made after the incubation of the plates at 30°C for 72 hours instead of at 37°C for 48 hours, a higher count, which gave a better indication of the infection, was obtained. Revised standard techniques were therefore published which incorporated these modifications (Ministry of

Agriculture, Fisheries and Food, 1955a, 1962).

Cousins (1962) points out that the techniques are given in these publications in some considerable detail in order to enable any results to be standardised. There must, nevertheless, be a compromise between simplicity, convenience and accuracy. The assumption is made that the rinse or swab removes a large and constant proportion of the organisms present on the surface being examined. This assumption is not, however, borne out by results obtained by Hoy and Rowlands (1948) who found that when a sterile rinse was passed through teat cup clusters five times, 60% of the organisms in clean clusters, but only 53% and 35% of the organisms present in two heavily contaminated clusters, were removed, the colony counts ranging from less than 500 to 10^8 per cluster. It follows, therefore, that rinses can only be expected to indicate the general level of bacterial contamination especially when complex surfaces such as milking machine clusters and pipelines are examined.

Bird (1957) described methods used for advisory purposes in other countries for the bacteriological evaluation of cleaning efficiency and proposed bacteriological standards for farm equipment. These were:-

Less than 10^4 colonies/ft^2	at $30^{\circ}C$ for 72 hours	Satisfactory
$10^4 - 4 \times 10^4/ft^2$	"	Fair
More than $4 \times 10^4/ft^2$	"	Unsatisfactory

That it is essential to use a standard technique when taking bacteriological samples, whether using rinses or swabs, can be appreciated since it has been shown by several workers that the proportion of total organisms removed from a surface is subject to much variation.

Cousins (1963) described the different methods available for the detection of residual organisms on milk handling equipment. Three different methods for the evaluation of cleaning efficiency of pipe-line milking equipment were described using rinses from which colony counts were obtained.

The first method is that of rinsing the individual components of the installation - clusters, receiver jars, pump, pipeline. Such a method permits the accurate identification of the source of any infection but it does necessitate the provision of special sterile fittings for the sampling and this system can be most time consuming.

The second method involves sampling of a sterile rinse which is circulated through the normal cleaning circuit. This method has the advantage of simplicity, but it does require the provision of an extremely large volume of sterile liquid. An additional disadvantage is that certain sections of the pipeline which are not used for milk, are included in the circuit, to complete the cleaning circuit. It was pointed out that lower counts were obtained by this method even if the circulation time was increased from 1 to 10 minutes. It was assumed that most of the organisms which can be removed by the rinsing are removed in the first minute.

The third and most commonly applied method consists of drawing 500 ml of sterile rinse through the plant from each cluster in turn, after which, a sample of the accumulated rinse is collected, usually from the receiver jars. Cousins (1963) stated that this third system appeared to be the most satisfactory since the counts agree with those from rinses of individual components. In addition, the rinse follows the path of the milk and there need be only one sample to examine.

Cousins (1963) discussed the effect of more than one rinse being passed through the plant, and reported that after as many as six consecutive rinses a measurable number of organisms were still removed. She suggested that micro-organisms accumulate in crevices and imperfections in the surface provided by rubber joints. This is also the opinion of Maxcy (1966) who claimed that as the concentration of residual soil is reduced on the equipment surfaces, the number of organisms is lowered as a result of the cleaning process, the concentration of soil, relative to the location of the residual organisms, is of importance. The soil which was present as residue after a cleaning process was measured by the dissipation of chlorine, the plant being flooded by a solution containing 2 p.p.m. available chlorine, for a period of 16 hours. Maxcy showed that the minimum level of soil dilution necessary to support significant growth was in the range of 1:1,000 - 1:10,000 when milk was used as the contaminating soil. Were such a concentration of soil spread evenly through the system it could be determined by chemical means as had been shown by previous work (Maxcy and Shahani, 1961). Since this was not possible it indicated that there was a localised concentration of the soils where bacteria proliferated. The use of radio-active techniques, using Na_{131} confirmed that the suspect areas were the joints in the pipeline, the pump and the dismountable couplings.

Eisenreich, Becker and Tewes (1953) in estimating the cleanliness of milking machines, and Holager (1963) suggested that sterile skim milk was a better rinsing medium than a sterile saline solution and Eisenreich et al added that the rinsing is more effective when carried out at 37°C (99°F).

Tjotta and Solberg (1955) suggested that a colony count of 50,000 organisms per cluster should be the maximum when rinsed with a sterile skim milk solution at 37°C (99°F) immediately before milking. The use of sterile skim milk, particularly when warm, would make the practice of taking routine rinse samples much more complicated, in that it would necessitate washing the plant again or the air dried or skim milk would present an additional cleaning hazard to subsequent cleaning operations. These disadvantages could, however, be overcome were the rinsing to be carried out immediately prior to the milking. This was the regular practice in advisory work in Scotland (Orr, 1966). It was found that when such a method was used, there was a very close correlation between the bacteriological results of the rinse and the first milk through the plant.

Johns and McClure (1961) carried out work to compare the efficiency of a pulsating rinse technique with a swab test for the hygienic condition of milking machines. The pulsating rinse technique was originally described by Claydon (1953) being subsequently modified by the West of Scotland Agricultural College (Orr, 1966). This modified technique was used by Johns and McClure (1961). It was found that the pulsating rinse test gave a much more reliable indication of the infection of milking machines than a non-pulsating rinse or a swab test. There is a growing recognition of the value of this technique and of the inadequacy of rinsing methods for the estimation of infection of rubber surfaces.

Richard and Auclair (1962) studied the proportion of organisms removed by successive pulsating rinses. They concluded that the technique showed sufficient accuracy for that purpose. They pointed out that the lack of correlation between pulsating rinse counts and milk counts below 10,000 indicated the masking effect of dilution. Similarly, other studies by the same authors showed that differences in pulsating rinse counts were not always reflected in counts on the milk. The apparent anomaly between high rinse counts which are not reflected in the bacteriological quality is explained by Baines (1962) and Cousins (1967) who pointed out that extremely high pipeline rinse counts result in a disproportionally small increase in the count of the first milk through since rinse counts are measured in organisms/ft^2 whilst milk is organisms/ml. The importance of pulsating rinse counts emphasises the importance of the rubber fittings in bacteriological quality as a result of the porous nature of the rubber. Whilst attention is generally directed towards specialised treatment of the rubber liners and, to a lesser extent, to the long milk tubes of the milking equipment, the condition of the rubber connecting sleeves is frequently overlooked. The joints of pipeline systems contribute very largely to the bacterial population of any pipeline.

The use of the sterile rinse as a means of assessing the bacteriological quality of the pipeline provides a reasonably simple effective and readily reproducible method. In order to identify particular sections which may be the source of infection, a more exhaustive method will need to be adopted.

EFFECT OF TEMPERATURE OF CIRCULATING SOLUTION

The temperature of the circulating solution, whether it contains a sterilant or not, is one of the principal factors for efficient cleansing and although within the direct control of the operator, is generally conceded to be the one which can be the most variable.

Thomas, who has carried out a considerable number of investigations in the bacteriological aspects of farm cleaning, stated (1964) that there is a distinct inverse association between the bacterial count of rinses of pipeline milking plants and the initial temperature of circulation. A decreasing initial circulation temperature is accompanied by an increasing incidence of heat labile coli-aerogenes.

Many attempts have been made to evaluate the effect of temperature on cleansing and many different values have been given for the lowest temperature which, it was considered permitted satisfactory cleansing. An examination of the literature shows that they are not in good agreement ranging from a minimum suggested temperature of $130^{\circ}F$ to $180^{\circ}F$.

$130^{\circ}F$	Baines (1962); Calbert (1958) and Thornborrow (1960).
$140^{\circ}F$	Swift, Alexander and Scarlett (1963).
$160^{\circ}F$	Cuthbert (1960; Edgell and Widdas (1964); Hommer and Babel (1957); Murray, Downey and Foote (1962); Murray and Foote (1963); Peters (1959); Phillips (1962).
$170^{\circ}F$	Fortney, Baker and Bird (1955).
$180^{\circ}F$	Clough (1965); Sheuring and Folds (1953).

Scheib (1966a) stated that, since the soiled surfaces have only been exposed to milk at body temperature, high temperatures should not be necessary to give good results. He reported the results of fluid studies which showed that a final temperature of the circulating detergent of about $110^{\circ}F$ after ten minutes circulation, or about $100^{\circ}F$ after twenty minutes circulation, resulted in excellent results.

Holland etal (1953) reported good results when the temperature of the circulating solution was about $120^{\circ}F$, and Snudden et al (1961) showed that when the temperature of the detergent solution started at 120°F and was allowed to fall naturally, the results after sanitation were comparable to maintaining the detergent solution at 150-160°F and allowing the temperature to drop naturally. Since the efficiency was measured by bacteriological methods, any subsequent sanitation would affect the efficiency of cleaning which could be assumed to be the result of higher temperatures.

Calbert (1958) reported widely quoted work relating the effect of the temperature with that of cleaning efficiency. He stated that satisfactory cleaning of pipelines could be effected by commencing with detergent solution temperature of 130-140°F although the circulating solution cooled down to as low as 90°F during the cleaning. Calbert (1958) used gravimetric rather than the more usual bacteriological methods for determining cleaning efficiency. Weighed plates of Pyrex glass or of two different finishes of stainless steel were soiled and cleaned by a controlled laboratory system. The results were found to be satisfactory. It was deemed unnecessary for any form of supplementary heating to maintain the temperature of the washing solution at 130-140°F. Although the results may have been quite satisfactory, when examined by these methods, it is felt that such a range of temperature would not prove to be as efficient when applied to a commercial installation, particularly with the additional cleaning hazard of rubber couplings and stall cock fittings, although a subsequent paper (Peters and Calbert, 1960) gave similar results achieved under commercial conditions.

Baines (1962) found that in an investigation into circulation cleaning on 12 farms, that the detergent steriliser was more effective when it was circulated at a minimum temperature of 120°F, and it was found that this necessitated an initial temperature of at least 170°F. Of the farms where the investigations were made, only one had a pipeline less than 100 ft. in length, this being the only milking parlour. The other farms were 'round-the-shed' installations with pipelines ranging from 150-320 feet.

Thiel (1959) described a series of investigations when the cleaning solution was made up with water at 145°F. The temperature dropped as soon as the solution came into contact with the metal equipment but during the 10 minute circulation it did not fall below 100°F. It was stated that careful bacteriological work showed that the results achieved were not uniformly satisfactory, although no suggestion was made as to how the results could have been improved.

The recommended temperature given by the West of Scotland Agricultural College (Advisory Leaflet 82, 1964) was of a detergent temperature of 180°F initially, not dropping below 120°F during the circulation. It is suggested that the first two jarsful of detergent be allowed to run to waste since this would assist to bring up the temperature of the circulating detergent. This practice, however, appears to be unnecessarily wasteful of detergent and this function could be equally well done by passing through the system approximately 5 gallons of water, as hot as can be obtained, and allowing this to run to waste immediately before the detergent circulation is commenced.

Phillips (1962) found that, in the cleaning by circulation methods of a milking parlour, when the detergent steriliser was circulated at 140°F for 10 minutes the bacteriological results were not satisfactory. When the temperature was increased to 155-160°F, good bacteriological results were obtained. The temperature was maintained by the direct injection of steam into the tank which contained the milking machine clusters. The injection of steam would, however, reduce the concentration of the circulating detergent. The evaluation of cleaning efficiency was, however, made by bacteriological means so that any increase in temperature would assist in reducing the bacterial population and make an apparent contribution to the cleaning.

Swift et al (1963) were of the opinion that, whereas a treatment using a detergent/sodium hypochlorite solution circulating at temperatures 140-150°F should, in theory, give commercially satisfactory results, there was not a sufficient margin of safety under general working conditions. They calculated that the cost of applying the higher temperatures (i.e. 180°F) was in the region of 5d. per day, but they considered that this additional cost was not justified provided that satisfactory results were being obtained by the correct application of lower (140-150°F) temperatures.

Thornborrow (1960) reported an investigation carried out by bacteriologists of the National Agricultural Advisory Service on 26 farms in England and Wales during February - September 1959. The temperatures ranged from 'cold' to 170°F. The bacterial count of equipment was lower when the temperature of the circulating solutions was above 130°F. It was noted that the use of heat (i.e. above 130°F) appeared to be beneficial whether used for the circulating wash solution or for the final rinse. This opinion is shared by other workers. Widdas (1950) suggested that the bacteriological results showed that the recommended methods of chemical sterilisation were not by themselves, sufficiently effective to obtain consistent satisfactory results and that additional heat treatment may be required. Cuthbert (1960) stated that circulation cleaning without the application of heat was not a worthwhile proposition and although improvements in the design of the equipment, and improvements in rubber fittings, to give more cleanable surfaces would assist in improving the results, the application of heat would still be essential. This assumption, however, is challenged by Daines (1962) who stated that since, with correct cleansing methods, equipment such as a farm milk bulk tank can be maintained in a satisfactory bacteriological condition, it should follow that, given correctly designed equipment and with the development of detergents and sterilants the problems which are being experienced at present could very largely be eliminated. Such an argument ignores the fact that the cleaning mechanisms are quite different - the manual cleaning of the large surface of bulk tanks can hardly be compared with the cleaning of complex pipeline systems by circulatory methods, although the recently introduced systems of spray cleaning farm milk bulk tanks could provide further information.

Fortney et al (1955) found that the cleaning of stainless steel pipelines by circulatory methods using 4 different detergents was improved when circulation was carried out at 170°F rather than at 130°F especially insofar as gaskets and bevels were concerned, the latter being the most difficult to cleanse. Bacterial counts were consistently lower when the cleansing was carried out at 150°F or more, than they were when cleaned by hand, presumably at lower temperatures.

Peters (1959) examined the effect of temperature on the cleaning of milk pipelines by circulation methods. An evaluation was made, using both gravimetric and radioactive techniques, on the effect of different temperatures. In both cases it was found that better results were obtained when cleaning was carried out at 160°F than at 85-140°F.

Smith (1957) recommended a temperature of 160°F for the circulation of pipelines. A similar value of 150-160°F during a circulation of 30 minutes was given by Hammer (1957) who suggested that a hot rinse at 135°F should follow, and cleansing be completed with a rinse containing 200 p.p.m. available chlorine immediately before milking.

Murray and Foote (1963) concluded that a circulation temperature of not less than 160°F gave better results than circulation at 145°F.

Edgell and Widdas (1964) reported that investigations carried out by the National Agricultural Advisory Service bacteriologists showed that, unless the initial temperature of the detergent/steriliser was at least 160°F and preferably higher, rinse counts of the plant tended to be so high as to be considered unsatisfactory.

The Ministry of Agriculture, Fisheries and Food (1959) recommended that until trials could show that chemical sterilisation alone could be used satisfactorily, there should either be adequate steam raising equipment or facilities for producing an adequate supply of water at 170°F.

As a result of an investigation carried out on 12 farms in England, Swift et al (1963) found that the most effective method was the use of cleansing solutions - i.e. detergent and hypochlorite - at a temperature of 180°F. It was found that the circulation of detergent without the inclusion of the hypochlorite gave less satisfactory results, which it was thought to be due to the temperature of 180^{o}F not being maintained during the circulation time of 10 minutes.

Official recommendations have been made of not less than 160^{o}F at the beginning of the circulation, and preferably higher initial temperatures 170-180^{o}F (Ministry of Agriculture, Fisheries and Food, 1966).

Shearing and Folds (1963) found, in the cleaning in place of glass pipelines, that at a circulation rate of 3 ft/sec. water at 190^{o}F satisfactorily sterilised the line.

Nokes and Tredennick (1965) investigated the efficiency of circulation cleaning under normal farm conditions at 33 farms in the South West of England and reported that an initial circulation temperature of 180^{o}F and over gave the best results. No indication is given of the drop in temperature which took place during the circulation.

Clough, Akam and Gant, (1965) described a once through circulation cleaning system using boiling water. The pipeline system was one which had been designed specifically for cleaning in place. They reported that work carried out in 1960-61 showed that with chemical disinfection at temperatures below 160°F rinse counts of the plant regularly exceeded 50,000/ft^2. Satisfactory rinse counts were achieved when boiling water was used after the chemical treatment to maintain a temperature of 170°F for 2 minutes. This was the intention of the installation - to heat all parts of the installation up to a temperature of at least 170°F for at least 2 minutes to ensure sterilisation. No detergent is used in this process, nitric or sulphamic acid being added to the heated water in order to prevent the deposition of calcium or magnesium salts in the vacuum/wash line, the vacuum line being used to complete the washing circuit. Near boiling water is supplied at the rate of 3 gallons per milking unit from a water heater and the requisite amount of nitric or sulphamic acid added from a container into the water line by means of a small orifice. The acid solution is drawn into the near boiling water during the first 2 minutes of the cleaning process, after which there is a further three minutes whilst the water is drawn through the system, back to the interceptor jars, through the milk pump to waste. It is claimed that the difficulties experienced with chemical sterilisation when detergent solutions are circulated at temperatures below 160°F have been overcome using this process and counts of less than 50,000/ft² have been consistently achieved.

Although this system has been developed along practical lines, it has been intended primarily for milking parlour installations. For 'round-the-shed' installations there would be problems in achieving the required temperature of 170°F unless there was available a considerable volume of boiling water. Such problems would not, however, be unsurmountable. The principal drawback would, however, be the prevention of boiling water escaping through the stall cocks. Being designed for vacuum operation, when the water in the pipeline is under pressure, there would be some leakage, particularly in the case of one type where the seal is effected by a flexible rubber flap (Fullwood) which is normally drawn by vacuum against the orifice.

From this review it may be seen that reports dealing with the effect of temperature on cleaning are not in agreement, largely because the effect of temperature alone could not be dissociated from other factors and also it is but rarely that any indication is given of the composition of the detergent which has been used during the investigation. In only a few cases are basic detergent formulations used so that the effect of any individual constituent is not so marked that it changes the effect of other factors under investigations. In work with circulation cleaning by the National Institute for Research in Dairying the cleaning compound used is that of sodium carbonate with the addition of 20% sodium hexametaphosphate as a water sequestrant. In much of the other work, however, the detergent used is much more sophisticated and the results are, very broadly, applicable only to the installation in the investigation. That the composition of detergent affects the efficiency of cleansing was shown by Lindamood, Finnegan and Graf (1955) who compared the efficiency of 6 detergents and detergent/sterilisers used in circulating cleaning. The results of a survey covering 6 months indicated that there was more variation between the cleaning ability of different detergents than between a higher circulation temperature or using a lower circulation temperature using the same detergent.

One of the most valuable contributions to studies of this aspect of cleaning are those of Jennings (1957a, 1963) who, using a laboratory installation and eliminating all other variables, directly related cleaning with temperature. Jennings measured the decrease in the radioactivity of films produced by in vitro labelled milks during a standard washing process. The majority of comparative work on cleaning efficiency and temperature uses bacteriological methods of evaluation, involving the number of the residual bacterial population. The measurement of the efficiency of cleaning using different methods is discussed elsewhere but insofar as an evaluation of a cleaning system is based on the bacteriological condition of the cleaned equipment it should not be overlooked that any bactericidal activity exhibited by the sterilant used cannot be dissociated from the bactericidal effect of the circulation temperatures of 140°F and above. This aspect is also emphasised by Cuthbert (1960).

Jennings (1957) reporting a study on the relationship of temperature with cleaning effectiveness, concluded that higher temperatures help cleaning but that turbulence is much more important. With lower turbulence - R_e 36,600 - higher temperatures are slightly more important.

The same author (Jennings, 1963) pointed out that the removal of milk solids from stainless steel by caustic soda solution in a circulation system could be treated mathematically in a similar manner to the speed of reaction between two chemicals.

A similar type of expression could be established to describe the rate of soil removal by a detergent. Measurement was effected by the use of standard test discs of 18:8 stainless steel soiled with 0.5 - 1.0 ml of P_{32} labelled homogenised milk. The discs were steamed to dryness and inserted in the pressure side of a centrifugal pump. The circulating liquid was pumped through a 1½ in. stainless steel pipe which was inclined at an angle of ½in/ft. in order to ensure flooding of the pipe section. Other possible variables were controlled - the cleaning solution was circulated at a controlled rate and the condition of high turbulence induced by it (equivalent to R_e of 550,000 or 29.4 ft/sec) ensured a constant concentration of the hydroxyl ion at the soiled surface, the detergent being regularly changed to ensure an adequate reserve of ions. The detergent used was sodium hydroxide at a concentration of 0.5 Molar.

The time in seconds was plotted against the percentage of soil removed, as measured by the reduction in radioactivity of the seeded test discs. The temperature of the cleaning solution was measured at 5 different temperatures increasing from 36° - 82°C (97° - 180°F), all other experimental conditions remaining the same, and from the results it was shown that there was an apparent linearity in the increase of the soil removed.

Jennings expressed the rate of soil removal by the formula:-

$$\frac{-dS}{dT} = K(S)\,(OH)^{-}$$

where S is the soil, expressed as a percentage of the original deposit; OH^{-} as the hydroxyl ion concentration; T time and K molar velocity constant.

By plotting log K against the reciprocal of the absolute temperature - i.e. expressing it as an Arrhenius* equation - linearity of soil removal was again shown. Under the test conditions, the removal of milk films by the use of solutions of sodium hydroxide was shown to increase by a factor of 1.6 for every 18°F rise in temperature in the range 115 - 180°F. When 0.2% NaOH was used for cleaning, cleaning was 5 times as fast at 180°F as at 115°F. There must obviously be an upper limit to this effect which would be brought about either by decomposition by heat of the detergent or by the interference by vapour pressure of the liquid. Jennings pointed out that the determination of K values could be used to evaluate precisely the reaction of specific detergents with specific soils, and also compatability and synergism with mixtures of detergents. Criticisms to these assumptions were answered in a subsequent paper (Bourne and Jennings, 1963) when it was shown that the conclusions could be supported by other workers (Utermohlen and Wallace, 1947, and Vaughn, Vittone and Bacon, 1941) who endeavoured to set up equations for the removal of soil, but both were hampered in eliminating all the variables. Utermohlen and Wallace were unable to separate the relative amounts of 'removable soil' and 'irremovable soil' and Vaughn <u>et al</u>, of whose work Utermohlen and Wallace was a continuation, selected a value for K by a method of trial and error, which affected the accuracy of K.

Continuing the work, Jennings felt that it was necessary to set up an expression which took into account the effect of temperature on the removal of soil by the action of the detergent - in this case, NaOH - and the removal of the soil by the action of the water.

A separate value was obtained for each and it was found that in the range of concentration of hydroxide ion - 0.5M NaOH - water, far from being inert, is the most active constituent in the detergent system, unless the comparison is on a mole for mole basis. With increasing effectiveness as a result of increasing temperature, the increase is greater for OH^- ion than with water.

In order to ensure the maximum efficiency of the cleaning system the three principal variable factors must be at the optimum value - detergent concentration, time of circulation and temperature - The temperature of the circulating solution is the most variable and it is necessary that it be as high as possible, that the pipeline system be warmed before the detergent circulation commences, and that, by the provision of adequate volume of solution in the detergent tank, this temperature be maintained. Factors which influence heat losses are discussed below but it is essential that the circulating detergent be circulated at a temperature in excess of 140°F, the temperature being taken at the outlet of the circulating system.

EFFECT OF TIME

Detergent manufacturers appear to be more unanimous in their recommendations for the time of circulation of detergent solutions than in the temperature of circulation. Manufacturers' recommendations for eight commonly used detergents in Scotland are shown below.

Name	Type	Temperature (°F)	Temperature (°C)	Time (min)
Alfa Laval	detergent	150-160	66-71	10
C.I.P.	detergent	150-180	66-82	15-20
Circlet	detergent	150-160		10-15
Circlor	detergent/steriliser	180	82	10
Dellarinse	detergent/steriliser	140-150	60-66	15-20
Fullcircle	detergent	170	77	20
Rinsan	detergent/steriliser	Hot		not given
Spiro-pep	detergent/steriliser	180	82	10

A circulation time of 10-20 minutes is usually given by both advisory and commercial sources (West of Scotland Agricultural College, 1964; Edinburgh and East of Scotland College of Agriculture;

undated; Murray, Downey and Foote, 1962; Holland, Shaul, Thickes, Windle, 1953; Fisker, 1949).

In most detergency studies, the time factor is normally constant, thus permitting studies to be made of other variables such as velocity, temperature, detergent composition or concentration. Time is the variable which can be most easily made uniform over any number of series of experiments. One early investigation (Rhodes and Brainerd, 1929) reported that log-log plots of detergency against time were linear and it was suggested that these slopes could be used as a basis for comparing detergent efficiency, but this does not appear to be confirmed by subsequent work by other investigators.

In the course of an investigation on the physico-cleaning relationships in cleaning hard surfaces, Bourne and Jennings (1961) found that extended continuous treatment had less cleaning effect than a short treatment. In their investigation the removal of radioactive labelled tristearin by 0.3M NaOH was measured using soiled stainless steel discs in a closed circulatory system. The work was carried out using pure tristearin with 10% C_{14} labelled tristearin as a tracer, since this compound is a stable saturated fat and its chemical and physical properties are well known. It was found that one cleaning treatment of only 10 seconds removed 25-27% of the soil whereas a cleaning treatment lasting 15 minutes or longer under the same conditions, removed only 13-21% of the soil. Continued cleaning up to as long as 4 hours resulted in but little difference.

Fortney, Baker and Bird (1955) pointed out that the time of circulation should be related to the type of soil, that for cold milk requiring a different period than for hot milk. They stated that the temperature of solutions used for circulation cleaning is more important than either time or velocity when the time of circulation is 20 minutes or longer. This latter point is confirmed and explained by Scheib (1966a) who in an investigation of the cleaning of pipeline circuits, pointed out that trouble may develop if the circulation is prolonged to such an extent that the temperature of the circulating solution drops to a point at which redeposition of soil may occur.

Scheib (1966a) found that he was able to obtain excellent results after 10 minutes circulation and he stated that even shorter periods may be effective.

Jennings, McKillop and Luick (1957) in carrying out an investigation on the effect of turbulence on cleaning efficiency, concluded that in relating time with turbulence, time may be decreased as turbulence is increased.

Possibly the most exhaustive work on the effect of the time of circulation on cleaning efficiency is that of Bourne and Jennings (1963). These workers studied the removal of thin films of radioactive tristearin from stainless steel test strips by sodium hydroxide solution in a circulation system. The detergent, consisting of 0.03M NaOH was pumped by a centrifugal pump through a vertical glass pipe in which the test pieces were placed. The detergent was then returned to a tank from which it was again recirculated. Provision was made for the quick draining of the system in order to prevent any additional soaking of the test pieces when the circulating pump was stopped. The temperature of the circulating detergent was maintained by a copper heating coil immersed in the tank which maintained the temperature of the circulating solution to within 0.2°C of the required temperature. The test strips were heated to the temperature in an oven and quickly inserted into the pipe section, when the solution was pumped through the system for the required time.

By plotting the log of the radioactivity count against the number of 10-second washing treatments, it was found that the plots, instead of being linear, as was expected, were curved for the first seven washings, after which it was linear. Even when the number of washings was continued to as many as 40 washing treatments, once the linearity of the plot had been established, it remained a straight line. The authors investigated the possible explanation of this phenomenon. It was pointed out that the linear part of the graph could be attributed to a layer of tristearin which represented approximately three molecular thicknesses, after taking into account the rugosity of the steel surface, which is given as about 4.

By extrapolating the linear part of the curve back to zero washes, and the extrapolate line subtracted from the curve,another straight line was obtained with a much sharper slope. It was postulated that these results could be satisfactorily explained by assuming that there were two different species of tristearin present and that each species was removed independently and simultaneously by a first order process and that the species represented by the sharp slope was removed at a faster rate than the other. This was removed completely in the first seven washes, (for all practical purposes) with the subsequent cleaning curve representing the removal of the other species only. Although this would have appeared to have been due to impurities in the tristearin, this was discounted by collecting the tristearin removed in the first few washing treatments, and a test strip soiled with this.

Such a strip exhibited identical characteristics as the others, which showed that this anomalous result was not the result of any impurities. Similarly, it was shown that the tristearin could not be in the form of different polymorphs, since the experiments were carried out above the melting point of the stable form.

Upon examination of the results obtained by other workers, investigating a wide range of soils and cleaning techniques, it was found that this phenomenon is not restricted to tristearin. Pflug, Hedrick, Kaufmann, Koppsler and Phiel (1961), in studying the removal of dried skimmed milk films from stainless steel, using a commercial detergent mixture, found that, in plotting the logarithm of the milk solids remaining on the cleaned surface against the number of washings, curves were obtained that became linear after about 10 washes. By applying the theory offered as an explanation by Bourne and Jennings to the results obtained by Pflug et al, traces were obtained which agreed reasonably closely to the theory expressed.

Other workers have shown cleaning curves as a function of time and in each case it can be seen that the curve follows the same shape, with the initial curve becoming linear after a specific number of washes - i.e. after a particular period of time. That this is true for many different soils which are being exposed to different cleaning operations, has been shown: dried skim milk on stainless steel (Pflug et al, 1961); dried milk on stainless steel (Jennings, 1959a); soil mixture on cotton cloth (Bacon and Smith, 1948); mixtures of different soils on cotton cloth (Utermohlen and Wallace, 1947, Utermohlen and Ryan, 1949).

Hucker, Emery and Winkle (1951) and Masurovsky and Jordan (1960) showed that with increasing soiling and washings of a pipeline system, there was a gradual accumulation of a residual soil layer. Applying the observations of Bourne and Jennings (1963) it can be stated that this residual soil would be indicated on the graph by the linear portion, referred to by them as species 2 soil. The so-called species 1 soil would be removed by the earlier washings, but only a part of the species 2. The latter would therefore tend to accumulate with increased washings and so result in the build up of a more resistant type of soil. Bourne and Jennings offered no explanation to explain the attraction that the species 2 soil has for the soiled surface but it was pointed out by them that such films would have quite an important bearing in the interpretation of any comparative detergency tests, although in a later paper (Bourne and Jennings, 1963) it was suggested that this soil exhibited a greater energy barrier which had to be overcome before it could be removed.

This build up of soil justifies the frequent use, which is recommended as a regular practice in the U.S.A., of an acid cleaner (Farms and Industrial Equipment Institute, undated). It is suggested that an acid cleaner solution be circulated through the entire system. In addition, the last rinse of the pipeline before draining, can be acidified. Whilst the acid is more generally applied as a post rinse treatment, some

some instances have been quoted (International Association of Milk and Food Environmental Sanitarians, 1966) where it has been used as a pre-rinse with equal success. The method of cleaning pipeline systems which have been developed in New Zealand incorporates an acid circulation once every week (Whittlestone and Phillips, 1955).

Scott, Whittlestone and Lutz (1962) compared the original alternating acid and alkali cleaning system with another using the same type of alkali every day which included a pre-milking rinse of phosphoric acid iodophor. The latter was shown to be more effective in preventing a build-up of milkstone that the alternating acid and alkali cleaning system with no greater significant corrosive characteristics. Johns (1967) described the use of a chlorinated alkaline detergent, with a pre-milking sterilising rinse of a low foaming iodophor which contained orthophosphoric acid.

It can be appreciated that this practice will control, if not remove, any deposition in the pipeline system. Clegg (1956) discussing the development of chemical sterilisation in England, observed that early investigational work at the National Institute for Research in Dairying at Reading, showed that the use of some detergents resulted in an 'invisible' film being built up on milk-contacting surfaces, the film not being removed by normal washing. Periodic descaling became a safeguard in the recommended technique. This build up, however, only appeared to occur in hard water areas and acid treatment was suggested at a frequency of once per month in all except soft water areas. That it is not necessary in soft water areas, with water hardness less than 3 gr/gall is also pointed out by the report of the International Association of Milk and Food Environmental Sanitarians, (1966). It is also stated that other methods which are successful have involved the use of sequestrants either incorporated with the detergent or added separately. Some milking machine manufacturers in North America supply an automatic acidifier with an automatic system of washing which adds a pre-determined amount of acid to the circulating rinse water.

The effect of time on the efficiency of cleaning was investigated by Nokes and Tredinnick (1965). The investigation was carried out under normal commercial conditions at 33 farms in the South West of England. The efficiency of cleaning was evaluated by bacteriological examination of rinses of the equipment. Of the 33 farms in the survey 7 were extended pipeline, 4 were parlours with jetters and 22 were parlours without jetters. Of all the farms examined the relationship between the initial circulation temperature and time of circulation were:

	Circulation Time	
Initial temperature	Less than 15 mins	15 mins and over
Less than 130°F	1	-
130-159°F	11	4
160-179°F	1	9
180°F and over	3	4

Relationship between initial solution temperature, time and bacteriological results

Temperature	Circulation Time (mins)	Bacteriological results: Satisfactory	Fairly Satisfactory	Unsatisfactory
Less than 130°F (54°C)	Less than 15	-	2	8
	15 and over	-	-	-
130-159°F (54-70°C)	Less than 15	15	8	87
	15 and over	7	7	33
160-179°F (71-81°C)	Less than 15	1	3	6
	15 and over	20	19	59
180°F and over (82°C and over)	Less than 15	15	5	11
	15 and over	15	6	25

These results indicate that there is no advantage from a cleaning point of view in circulating for more than 15 minutes.

This conclusion is supported by a further study of Jennings (1963b) who showed that one mechanism involved in cleaning, the so-called 'Dupre effect', arises from the movement of the air-detergent interface over the soiled surface. By comparing two similar test strips, one being exposed to the action of the moving detergent for 60 seconds during which time the air/detergent interface moved over the strip 16 times. The other strip was in the circulating detergent 80 seconds during which time the air/detergent interface moved across the test strip twice. The amount of soil removed, measured by residual radioactivity was 75.3% and 29.2% respectively.

It was shown that a short cleaning period (2 minutes, consisting of twelve 2-second treatments) removed 75% of the soil, whereas one continuous treatment of 15 minutes duration removed only 15% of the soil. A previous paper (Bourne and Jennings, 1961) had shown that the small cleaning treatment associated with long continuous cleaning times coincided with the rolling up of the soil into lumps which were very resistant to removal by the detergent.

The effect of admitting air into the circulating system, resulting in 'air brushing' would subscribe to the 'Dupre effect' under commercial cleaning practice and would contribute to the scrubbing effect of the detergent.

It does appear therefore that this weight of evidence supports the conclusion of Nokes and Tredinnick (1965) that no advantage is gained by continuing the circulation longer than 15 minutes and indeed this would prevent the detergent solution becoming too cool which would adversely affect its soil dispersal characteristics and thus prevent efficient rinsing.

In North America there are many areas where pipelines are cleaned by circulation for only 10 minutes (International Association of Milk and Food Environmental Sanitarians, 1966) instead of the usual 20 minutes, although it is pointed out that some producers have had to return to the twenty minute wash, since the shorter circulation time gave unsatisfactory results. With the shorter circulation time the water temperature would not drop to the point at which precipitation of soil would occur.

It can therefore be concluded that the circulation time makes a greater contribution to the efficient cleaning of pipelines than is generally appreciated. An excessively long period of circulation may reduce the amount of soil removed if the temperature of the detergent drops too low. There is a minimal time which appears to be ten minutes which only just permits satisfactory cleaning of the pipeline to take place. The time of circulation must be related to other factors amongst which must be turbulence of the circulating solution, efficiency of the detergent and temperature. Where any system of circulation cleaning is established which gives satisfactory results, time of circulation must remain at the same figure unless other variables are altered, or else the efficiency of cleaning will be adversely affected. The use of automatic systems to control the time and sequence of the cleaning operations offer great advantages in that a degree of uniform efficiency can be set up which would be quite independent of manual control.

THE EFFECT OF AIR AND TURBULENCE

It is necessary for the detergent solution to be circulated at a flow rate which is sufficient to induce a turbulent flow in the circulating liquid. It is most unlikely that soil can be completely removed by the detergent action of the solution in contact with the soiled surface. Energy must be applied to supplement the chemical and physical action of the detergent in the form of heat or, more frequently, mechanical energy. The conventional method of cleaning by manually brushing the soiled surface is a simple example of the application of energy to assist in soil removal. In circulation cleaning, as in spray cleaning, this energy source is replaced by the friction between the deposited soil and the cleaning solution flowing over it. The greater the velocity of the flow of the cleaning solution, the greater will be the opportunity for emulsification and solubilising by the detergent.

Despite the fact that it is usual to refer to the velocity of the cleaning solution, it is more correct to speak of the turbulence induced in it. Turbulence is a manifestation of velocity but only if the velocity of the circulating solution is the only variable in the Reynolds' Number (Reynolds, 1901). This value describes the pattern of flow of a fluid in a tube and has been shown to be a function of a group of variables which form a dimensionless number. It is usually represented by the equation $R_e = \frac{DV}{K}$ where D is the diameter of the tube in feet, V is the velocity of the fluid in feet per second and K is the kinematic viscosity in square feet per second.

Jennings, McKillop and Luick (1957) point out that when such factors as diameter, or diameter and velocity are changed, the relationship becomes more complicated and velocity alone cannot be used to describe turbulence.

Jennings et al. (1957) set up equipment to determine the effect of solution flow for different values of Reynolds' Number. The equipment permitted an accurate velocity control and evaluation of flow conditions simultaneously.

By using the same detergent at a standardised concentration and maintaining a constant temperature of 60°C is was found possible to measure quantitatively the effect of different Reynolds' Numbers. There was a sharp break in cleaning effectiveness at an R_e of 25,000 measured by residual activity on the test discs. The discs were of stainless steel which had been previously soiled with milk to which had been added P_{32}. Further increases in turbulence were contributed by increased velocity of the cleaning solution. A comparison of the curves from data obtained by measuring different test sections showed a close correlation, and, on this basis, it was concluded that data obtained with one test section applied equally well to the cleaning operation. It was noted that there was significantly little cleaning action when the Reynolds' Numbers were low.

Hankinson, Carver, Chong and Gordon (1965) point out that turbulent flow usually occurs at R_e values above 3,000 and laminar flow below 2,000.

Reynolds' Numbers provide a measure of friction forces or shear stresses at the pipe surface in relation to inertia forces and it was suggested that this value would be a better basis for circulation cleaning requirements than the 5 feet per second which is generally quoted and which does not take into account the pipe diameter nor the temperature of the circulating liquid.

Jennings et al. (1957) carrying out further work in this series of investigations with turbulence at a constant value, but varying the temperature of the circulating solution, showed that, although higher temperatures helped cleaning, turbulence is much more important. However, in the low turbulence range - R_e 36,000 compared with R_e of 72,000 - temperature seemed to be slightly more important than turbulence.

By varying the detergent constituents, it was shown that the effect of turbulence or temperature became less important as the physical and chemical effectiveness of the detergent increased. By relating the effect of time and turbulence in the cleaning efficiency of a circulatory system, it was concluded that, for satisfactory cleaning, time may be increased as turbulence is decreased. This conclusion does not take into account, however, the possible deleterious effect that extended time of circulation could have on the effectiveness of the detergent, since as the temperature decreases, its soil retention powers would be lowered.

Jennings (1959) stated that the analysis of experimental data showed that plots of soil remaining on tests discs were best satisfied by two straight lines intersecting at about R_e of 25,000 which is equivalent to a velocity of 1.3 ft/sec. in a 1½ in. line. Changes in temperature of the circulating fluid or the detergent composition would of course alter these values, but it can be assumed that once minimal conditions are satisfied, increased turbulence would be beneficial to the cleaning efficiency.

Holland, Shaul, Thiokas and Windle (1953) and Parker, Elliker, Nelson, Richardson and Wilster (1953) claimed that the velocity did not effect the cleaning efficiency of pipes, but these conclusions are quite at variance with other workers.

Phillips (1958) reported that increased rates of circulation resulted in more efficient cleaning of milking machines and Smith (1957) recommended that the cleaning liquid be circulated through the system at 5 ft/sec. this being based on an R_e of 100,000 in a 1½ in. pipeline.

Fortney, Baker and Bird (1955) showed that velocities as low at 2 ft/sec gave satisfactory cleaning when used at 150°F or above. It was suggested that this was due to increased heat penetration at higher temperatures. At lower temperatures - 130°F for 10 minutes - it was found that circulation at 7 ft/sec gave better results than at 2 ft/sec. These workers stated that the velocity of the circulating solution is not related to the efficiency of cleaning of pipeline fittings - bends and gaskets - which they found to be the most difficult sections of the installation to clean. Temperature is more important than velocity in cleaning these parts of the system, or, when the circulation is 20 minutes or more, time becomes more important than velocity. Their conclusions, however, were based on bacteriological evaluations rather than on an estimation of soil removal. Whilst this does not invalidate their conclusions, it does not necessarily follow from their results that increased temperatures improve the cleaning efficiency. It may only indicate increased bactericidal effect of the circulating solution as a result of the higher temperature.

In the discussion concerning the flow rate in 'In Place Cleaning of Dairy Equipment' (Society of Dairy Technology, 1959) it is stated that, in very favourable circumstances, where the detergent strength is high and the pipe bore smooth, satisfactory results can be obtained at velocities less than 5 ft/sec, but this qualification would not apply to farm installations in the United Kingdom since, because of the method of connecting lengths of pipeline by means of rubber sleeves and also the obstructions offered by stall cocks, the bore could not be considered sufficiently smooth. The pipeline velocity of 5 ft/sec related to flow rate through a stainless steel pipe of $1\frac{1}{2}$ in. (37.6 m.m.) diameter would correspond to a flow rate 1,200 gal/hour. Jennings et al (1957) have calculated that this would correspond to a Reynolds Number of approximately 100,000. With the usual size of pipeline in use in pipeline milkers in the United Kingdom of $1\frac{1}{4}$ in. (31.7 m.m.) the Reynolds number would be 82,000 and the flow rate 800 gal/hour. With a glass pipeline of 1 in. internal diameter (25.4 m.m.), the flow rate will be approximately 500 gal/hour and the Reynolds number approximately 66,000. It is necessary that, where there are any small obstructions or pockets this minimum velocity should be increased. Where the cleaning solution passes stagnant pockets or areas, the velocity would be decreased and flow conditions would then be unsatisfactory. In a horizontal line the flow should not be permitted to fall below 3 ft/sec since below this figure the air contained in the circulating solution may separate and form pockets, thus preventing some of the soiled surface coming into contact with the cleaning action of the circulating solution.

The velocity of the cleaning solutions in pipelines in the United Kingdom is dependent upon the vacuum pump, which is used to draw the cleaning solution through the system. Should the capacity of the vacuum pump be inadequate the velocity would be decreased with a consequent serious drop in the cleaning efficiency. In a survey of milking equipment carried out in the South West of Scotland, Fyfe and McFarlane (1965) found that the vacuum pumps were operating at a satisfactory level at only 3.5% of the farms examined. In addition, 96.5% of the installations had inadequate vacuum reserve. Pipeline systems of milking require a greater reserve than bucket units since the milking buckets provide small local vacuum reserves. On these figures, therefore the vacuum pumps would often be incapable of providing sufficient flow rate of the cleaning solution through pipeline installations.

Whilst there is no indication as to the number of pipeline installations included in their investigations, it appears that attention would require to be paid to the capacity and efficiency of the vacuum pump since not only would milking efficiency fall off, but that any circulation cleaning would be unsatisfactory.

Since the vacuum pump is used to draw the detergent solution through the pipeline, the system would be under reduced pressure, and any leaks would permit the ingress of air. Since leaks are invariably present, circulating liquids therefore contain air, and it has been found that the "scrubbing" action of this entrained air does assist in the cleansing efficiency and can also affect the turbulence of the solution. The admission of air and the turbulence of the liquids are thus inter-related (Bourne and Jennings, 1961).

Air may be present in three forms in the circulating liquid system - dissolved, occluded bubbles or 'slugs', or foam. Jennings (1959a) found that airleaks contributed to cleaning. In an investigation concerning the effect of foam formation and air inclusion in the circulating system, he found that there was a relationship between the position of air leaks in the system, the volume of air introduced, and the addition of antifoam to the detergent. Any formation of foam in the line would adversely affect the cleaning efficiency by preventing all the soiled surface coming into contact with the detergent solution and also by providing a cushion against the scrubbing action of the circulating solution. Where foaming occurs as a result of the formulation of the detergent an antifoam may be added but it is more satisfactory for the composition of the detergent to be balanced in order to prevent foaming. In measuring cleaning efficiency by the removal of the radioactive soil from the test discs, Jennings (1959a) found that there were no detectable differences with antifoam when the test section was on the pressure side of the system. With the test section in the suction - i.e. the vacuum - side of the system the presence of antifoam interfered with the cleaning efficiency. Jennings considered this was not due to interference by the detergent or the detergent/surface interface. Since the anti-foam acted by reducing the solution/air interface, it would therefore decrease the scrubbing action of any bubbles and occluded air and would thus affect only the cleaning effect on the suction side where the air was drawn into the system. If this reasoning was correct, occluded air assisted cleaning efficiency and air locks in the system would assist the cleaning process. In the absence of antifoam the result was most striking, the air contributing to the cleaning efficiency. Reporting later work, Jennings (1959b) showed that cleaning was more effective at reduced pressure and that by merely repositioning the pump so that it pulled rather than pushed the cleaning solution through the system the efficiency could be increased still further.

Milking machine manufacturers advise cleaning teatcup assemblies by drawing detergent solution through them and lifting them occasionally to permit the ingress of air. Where the units are cleaned as part of the circulation cleaning circuit as is invariably the case, they are suspended in the washing trough with the ends of the teat cups under the surface of the liquid and the free end of the long milk tube attached to a manifold which forms one end of the cleaning circuit of the pipeline. The air which is admitted to the system enters through the air bleed in the clawpiece. This air bleed is to lift the milk from the clawpiece to the pipeline. With some installations the manufacturer recommends that the returning cleaning detergent be pumped back through the clusters from the washtrough. Where this is so, there would be no air drawn into the circulating system from the clusters, but the pumped cleaning solution would pass through the teat cups at a greater flow and would thus avoid pockets being formed behind the neck of the liners. It is claimed by the manufacturers that this reverse flow method is more effective and also that the entrance of entrained air cools the circulating solution but this latter fact is not supported by any experimental proof.

Bourne and Jennings (1961) investigated some physico-chemical relationships in cleaning hard surfaces and found that soil was removed by two different mechanisms, one dependent on time, the other independent of time. They showed (1961, 1963) that under the experimental conditions of studying the removal of C_{14} labelled tristearin from stainless steel, most of the soil was removed by the time independent system which they called the 'Dupre effect' in view of the equations derived by Dupre in 1869 (Adam, 1941). The 'Dupre effect' arises from the air-detergent interface which advances over the soiled surface and is independent of the flow rate at all rates of flow. In most of the experiments described, this mechanism accounted for about 90% removal of the soil. In a previous paper (Bourne and Jennings, 1961) it was found that in a model circulation system using a chemically pure soil, the soil behaved as if it were composed of two different fractions. These two fractions were called by them species 1 and species 2 soil.

The former was shown to be time dependent and the latter time independent. The flow mechanism for the removal of species 2 soil was absent at flow rates of 2 lb/sec and less, but present at flow rates of 3.2 lb/sec and higher. No explanation was offered for this minimum flow rate, but it was suggested that this could be an example of the energy barrier described by Kling and Lange (1960) which had to be overcome before soil is removed from a surface. Species 1 soil appeared to be less tightly bound to the surface since, over the range of flow rate studies by Bourne and Jennings (1961) this type of soil showed no such threshold flow rate.

Jennings _et al_. (1957) found in the removal of milk films from stainless steel by circulatory methods, a threshold equivalent of approximately R_e 50,000. Below this value, soil removal was independent of flow rate and above it, soil removal was directly proportional to it.

In the cleaning of milk pipelines by

circulation methods the flow rate is largely controlled by the capacity and efficiency of the vacuum pump. This again emphasises the importance of the pump being efficiently maintained and that it is of the correct capacity for the length of pipeline and requirements of other ancillary equipment. The actual flow rate of the cleaning solution is difficult to measure because of the entrained air which is circulated with the liquid, and also where stainless steel milk piping is used, visual measurement is impossible. With the quantity of vacuum necessary to operate the milking equipment properly and also carry the milk through the pipeline, the desired minimum of fluid velocity during circulation cleaning can be achieved. The inclusion of air must be controlled since an excess would result in frothing. Such frothing would prevent the cleaning action of the detergent solution contacting the soiled surfaces in addition to filling the discharge vessels with froth. The propensity of different detergent mixtures towards the formation of foam varies considerably and depends primarily on their formulation. The air intake can be controlled by ensuring that all stall cocks and other fittings are vacuum tight and that the only air which is being admitted to the circulating system is through the air bleeds at the clawpiece.

The contribution of entrained air and the turbulence of the circulating solution to the efficiency of cleaning are inter-related. The maintenance of the correct vacuum necessary to perform both the milking and the drawing of milk through the pipeline is adequate to produce the necessary degree of turbulence in the circulating solution. Many installations, however, have inadequate vacuum reserves. The admission of air increases the cleaning efficiency but the volume admitted should be controlled. Excessive air will seriously limit the efficiency of the circulation cleaning.

EFFECT OF DETERGENTS AND STERILANTS ON THE CONSTITUENT MATERIALS OF PIPELINES

Problems concerning corrosion would appear at first to be an anachronism in view of the extensive use which has been made of stainless steel, glass and plastics in the manufacture of modern milking machine equipment, pipelines and fittings. It must not be overlooked, however, that stainless steel itself is not corrosion-proof, merely corrosion resistant. The broad picture of the corrosion of stainless steel is discussed by Botham (1956).

A common source of corrosive damage to equipment is the use of sodium hypochlorite solutions. Whilst the corrosive characteristic of this compound is often depressed in proprietary compounds by the incorporation of inhibitors, the control of corrosion is best exercised by the immediate and adequate flushing of the chlorine-bearing solutions from the equipment.

MacKenzie and Dick (1959) indicated that di-sodium hydrogen orthophosphate and tri-sodium orthophosphate inhibited the corrosion of stainless steel, aluminium and tin plate, when they were used with sodium hypochlorite with 200 p.p.m. available chlorine. It was pointed out that this inhibitory action varied with the metal, the concentration of the available chlorine and the ratio of the di- to tri-sodium orthophosphate. Primarily for this reason, the use of plated metals is to be avoided in circulation cleaning equipment. Although such equipment is not used in the actual pipeline, they can be often encountered in ancillary equipment particularly clawpieces and those milk pumps where the pump body is of plated brass. In addition, the older types of pipes with screwed fittings, which were used on the pressure side of the pump were often plated, and such fittings are often incorporated into a new circulatory system. In all these instances, stainless steel components are available. The use of sodium hypochlorite solution for sterilisation results in the rapid removal of the plating, exposing the copper and it is this, in addition to the hazard presented by the roughened surface, which may result in serious defects. A frequent defect of this nature occurs where the releaser jars are fitted with plated floats.

Where the copper is exposed, then the milk and copper reacts with quite serious defects in the flavour of the milk. In addition, however, there is the additional problem afforded by the adsorption of copper on to the stainless steel. This is described by Dunkley and King (1959) who showed that, under some conditions, dissolved copper becomes associated with stainless steel in a form which is readily available for the contamination of milk. In this manner, a small amount of copper nickel alloy can cause disproportionally large copper contamination of milk. It was found that the adsorption of the copper was appreciable in the range of pH 6-10, especially in the presence of sodium hypochlorite. The factors which influenced the adsorption of the copper included the temperature, the concentration of the copper in the solution, and the time of exposure. At low or very high pH values, the amount of adsorption was slight or absent, as it was in the presence of a chelating agent (sodium salts of ethylendiamine-tetra-acetic acid). It was found that the adsorbed copper was not removed by rinsing with water, but largely removed by the chelating agent or milk - milk possesses some chelating power - or by the use of hot nitric acid. The chelating power of milk may cause some apparent conflicting evidence in that deposits can be laid down in the whole cleaning circuit, but upon inspection can only be seen in that part of the circuit where the milk is not exposed to the pipeline. This would at first appear that the fault is only in the cleaning part of the circuit.

Merrill and Jensen (1962) attempted to set up a method of measuring metal loss from stainless steels caused by alkaline detergents. It was postulated that the stainless steel removal could be determined quantitatively by analysing the used detergent solution for chromium. Chromium was used as the index of corrosion since it is not present in natural water but is contained in stainless steel. The presence of chromium, therefore, in the used detergent solution was indicative of corrosion. Furthermore, the method used for the evaluation of chromium, using diphenylcarbazide, is sensitive to microgram quantities of chromium. In a limited laboratory investigation, marked differences were noted in chromium loss, proportional to the amount of chlorine present in the chlorinated tri-sodium orthophosphate used in the tests. On repeating the examination with proprietary chlorinated alkaline detergents being used to clean stainless steel piping, it was found that the loss of metal from the stainless steel was of small magnitude for any one alkaline detergent exposure period. This report indicates that, with further modifications to this system of testing, it would provide a simple rapid method of stainless steel corrosion evaluation.

In early installations of the 'round-the-shed' systems of milk handling, there was the tendency to incorporate lengths of galvanised water piping in the system for the completion of the washing circuit. The inclusion of such material, primarily to reduce the cost of the installation, was assumed to be quite satisfactory since it would be only used for the circulation of the washing solutions.

Several instances had been found (West of Scotland Agricultural College 1966) where producers had been experiencing trouble with milk of an unsatisfactory bacteriological quality the cause of which was not readily apparent. In other instances a fault had been noted of a deposit in the milk pipeline which would not respond to the normal methods of removal such as acid descalant circulation. On inspection of such installations it was found that the inside of the galvanised pipeline used to complete the washing circu it was extremely corroded although the external appearance of the pipe gave no indication of this condition and this was assumed to contribute to these defects. Such defects did not become apparent until the installation had been in use for some time, which would indeed be the case were the galvanised pipeline a contributing factor. Such damage would be important in three ways; firstly, the eventual penetration of the steel pipe would necessitate the replacement of the pipes in question: secondly, the corroded surface would offer an additional cleaning hazard since the pitted and roughened surface would offer cover to bacterial infection, such infection being seeded during the initial flushing of the plant residues from the system: thirdly, there is a risk that, under certain conditions, there could be a deposit laid down in the milk lines as a result of the products of corrosion being circulated through the cleaning circuit.

Acid descalants, which would have had a severe corrosive effect, had not been included in the normal cleaning treatments. The deposit found within the pipeline successfully withstood successive treatments, not only of the alkaline detergents, but also acid compounds based on orthophosphate acid, in attempts to remove the deposit. In one instance, the cause was found to be a supplementary heating element, incorporated in the circuit to assist in the maintenance of a satisfactory temperature of the circulating solution, the galvanising of the element being removed during the cleaning process. Although the heating element had been installed in the connecting pipe-line, the products of corrosion were laid down in the milk pipelines. With other installations, the cause of similar deposits were found to be the use of galvanised steel pipes which were used to complete the cleaning circuits, or were used in the construction of the milking cluster manifolds, those fittings being found to be corroded and rusty on the inside. These were replaced with either glass or polypropylene pipes which exhibited no corrosive defects after three years daily use.

The removal of the zinc from the galvanised pipes by alkaline detergents is not surprising since it is amphoteric but this would not account for any deposit in the stainless steel line. The composition of such a deposit was removed by a stainless steel spatula and submitted to a spectrographic examination. The deposit was shown to be principally iron, with traces of sodium and nickel. Copper, lead and tin together constituted

1% and zinc was 3% of the total. Since it could not be shown by analysis that such a quantity of zinc was present in the water, it could only have been derived from the galvanising of the pipes. An investigation was therefore set up to try and determine the cause of this deposit and thus to be able to recommend action to prevent its occurrence.

EXPERIMENTAL

<u>Method</u> 1.

Nine pieces of ½ in (12.7 m.m.) diameter galvanised water pipe, 3 in (76 m.m.) long, similar to that used in milking installations, and a corresponding piece of ½ in (12.7 m.m.) diameter 18:8 stainless steel were immersed in a 0.25% (w/V) solution of various detergent constituents - <u>tri</u>-sodium orthophosphate, sodium carbonate, sodium metasilicate - and these were set aside for approximately seven days at different temperatures, ambient, 22°C and 37°C.

<u>Results</u>

At the end of this time, it was noted that, whilst there was a substantial removal of the zinc from the pipes, this remained as a sludge in the bottom of the test bottles. Temperature appeared to have no effect on the extent or behaviour of the sludge.

Method 2.

In view of the results obtained above, similar tests were carried out using five proprietary detergents instead of the single detergent constituents. Again the test bottles were examined at the end of seven days.

Results

The results when examined at the end of the seven days were identical with those obtained with individual constituents, the sludge remaining at the bottom of the bottles, except for two detergents. With these two detergents, the galvanised pipe was again attacked, but the pieces of stainless steel which were in the same test bottle were covered by a grey incrustation which varied in intensity but was extremely difficult to remove, and upon analysis was shown to be zinc. This deposition occurred whether the stainless steel tubes were in direct contact with the galvanised pipes or were separated from it but within the same solution.

Discussion

On examining the composition of the different detergents, it was found that the two detergents which resulted in the deposition of the 'bloom' contained one of the sodium salts of ethylendiamine-tetra-acetic acid, these compounds being absent from the other detergents.

Method 3.

A further series of tests were then set up, where the lengths of galvanised pipe and stainless steel were immersed in the different sodium salts of the ethylendiaminetetra-acetic acid - di-sodium, tri-sodium and tetra-sodium - and held for 14 days at different temperatures - ambient, 22°C and 37°C. The concentration was approximately equal to that of the sodium salts of the ethylendiamine-tetra-acetic acid present in a solution of a proprietary detergent used at the recommended rate i.e. 0.0125%.

Results

At the end of this time the test pieces of pipe were examined and in every case there was an attack on the galvanising of the steel tubes and the characteristic 'bloom' was deposited on the surface of the stainless steel pipe sections. Temperature had no effect on the rate or extent of deposition.

Discussion

The sodium salts of ethylendiaminetetra-acetic acid form stable complexes with metallic ions. These complexes are inactive in solution and do not participate in reactions which would normally be expected of the metallic ion. A similar reaction occurs with the condensed phosphates, such as tripolyphosphate, tetrapolyphosphate and hexametaphosphate, but the complexes so formed are not so stable.

The sequestration of metallic ions by ethylendiaminetetra-acetic acid and its salts are effected in a particular order and this preferential sequence is dependent on pH and the nature of the solution.

Preferential chelation of different metals by ethylendiaminetetra-acetic acid salts at different pH values

(Smith, 1959)

Solution pH	Order of chelation from left to right
4.0	Cr Cu Ni Pb Co
6.5	Ni Cu Co Zn Cd Ca
8.65	Ni Co Cu Zn Cd Ca Mg Sr Ba
11.0	Co Ni Cu Zn Cd Ca Mg Sr Ba

The pH was measured in a buffer containing phosphate and carbonate ions.

The metals on the left are more strongly chelated than those on the right. Any metal, therefore, will be chelated in preference to those on the right and will displace any metal to its right from its chelate compound with an ethylendiaminetetra-acetic acid salts.

It was shown that the zinc coating of the galvanised pipe would be removed by any ethylendiaminetetra-acetates, but this characteristic is shared by many other alkaline salts, whereas in the latter case, there does not appear to be any subsequent deposition on the stainless steel pipe, nor has it been found possible to make any deposit on glass. It is suggested, therefore, that there must be a reaction between the pipe and the chelated ethylendiamine zinc acetate in contact with it.

By an examination of the table above, it can be seen that the nickel or chromium would be chelated at the expense of zinc, and since both are constituents of stainless steel, it is suggested that the zinc is laid down as a result of the chelation of these metals. This fails to explain, however, why such a deposit cannot be removed by the circulation of further alkaline detergents or acid descalants.

The corrosive nature of the ethylendiaminetetra-acetic acid salts is not new. Whittlestone and Lutz (1962) in examining the stability of aluminium tinned copper, half tinned copper, stainless steel and 'dairy metal' in 5 different detergent formulations found that the addition of ethylendiaminetetra-acetate compounds increased the corrosiveness for the aluminium and tinned copper. Jensen and Claybaugh (1951) in an examination of the comparative chelating properties of ethylendiaminetetra-acetates and the condensed phosphates noted that there were some indications that the former salts were more corrosive.

Further work by Jensen (196[illegible]) reported the corrosive effects of condensed phosphates and ethylendiaminetetra-acetate on tinned steel in the presence of different concentrations of sodium metasilicate. It was shown that increasing concentrations of the latter salt diminished the corrosive effect of the condensed phosphate, but appeared to have little or no effect on the other salt. Ethylendiaminetetra-acetates were practically twice as corrosive as condensed phosphate when no metasilicate was present.

Whittlestone, Fell, Calder and Galvin (1963) described an apparatus which has been devised for the express purpose of determining the suitability of materials used for the manufacture of milking equipment and which permits an accelerated assessment of any corrosive effects of any detergent formulations of constituents on such equipment. The instrument consists of most of the components of a normal milking machine assembled so that milk and the cleaning solutions can pass through the unit at a fixed rate. A wide variety of different treatments can be given by a programme controlled which operates the simulated milking, cold water rinse, hot detergent rinse, hot water rinse and a brief drying period. The cycle can be repeated automatically every 50 minutes thus producing conditions which would be found in the field only after considerable operating time.

Corrosion of stainless steel can also be caused by electrolytic action and the leakage of electrical current, particularly from electrical pulsation equipment, can result in the corrosion of adjacent stainless steel fittings. This would be a fault of installation, in that care must be taken to ensure that the contact of dissimilar metals is prevented.

By the operation of cleaning in place techniques of cleaning, regular inspection of the milk contacting surfaces is not made. For this reason any corrosive tendencies could be serious before they were appreciated since they would require to be manifested in order to be noticed.

Control of the factors which could contribute to corrosion would include:

(a) Use only of detergents which have been formulated for circulation cleaning and which are compatible with the water being used.

(b) Whether chlorine bearing compounds are used alone or in conjunction with detergents, they must be thoroughly and immediately flushed from the system.

(c) All cleaning solutions - detergents, sterilants or acids, must be allowed to come into contact only with materials of stainless steel, glass or resistant plastic.

(d) By careful installation, all electrically operated equipment must be satisfactorily insulated from milk lines and all dissimilar metallic contact be avoided.

(e) By inspection at regular intervals, any corrosive attack should be noted and remedial action taken where necessary.

EFFECT OF DETERGENT COMPOSITION

The composition of the detergent used for the cleaning of milking equipment is more important for systems that are cleaned in place than by handwashing. Not only can any deficiencies in the effectiveness of the detergent be compensated for by assiduous physical effort on the part of the operator, but certain circulating detergent fractions may cause insidious corrosion since equipment cleaned in place is inspected infrequently.

No single constituent of a detergent is capable of possessing to the full the properties necessary to clean the soiled milking equipment. The soil may range from simple cold milk residues to air-dried milk solids. Therefore, except in a few isolated instances, the use of a compounded mixture of detergent constituents combining many properties is necessary for satisfactory cleaning.

The effectiveness of cleansing of any system is usually estimated by the determination of viable organisms remaining on the cleaned surface in conjunction with an occasional visual inspection. Kaufmann, Hedrick, Pflug and Phiel (1960a) however, have shown that there is not necessarily a relationship between physical cleanliness and bacterial sterility, and cleaning efficiency cannot therefore be entirely related to measurement by bacteriological methods. It should be pointed out, however, since cleaned equipment can be considered to be satisfactory if there are no residual bacteria to contaminate any milk contacting surfaces, that bacteriological techniques do afford a reasonable method of assessing the efficiency of the cleaning operation.

The use of radioactive techniques have been shown to be useful in providing quantitative date of cleaning efficiency and function by the measurement of the radioactivity of the residual soil. Lisboa (1967) found that in the determination of detergent efficiency it was originally found necessary to make the test conditions more stringent since ordinary milk films were easily removed by a circulation cleaning system. The time of circulation when using such techniques, was therefore considerably shortened in order to permit a measurable radioactive residue. Whilst such a practice, however, may have provided an accurate comparative means of detergent evaluation, of necessity capable of being accurately reproduced, it could not be related to any results obtained under normal commercial practice with a circulation time which would be considerably longer. This defect, however, can be overcome by applying several layers of radioactive film before commencing the washing operation. It was suggested, however, that a more reliable and easier method could be the use of the Lisboa tube test (1959).

By the use of Kjeldhal analysis of the used detergent solution Maxcy and Shahani (1960), were able to obtain a sensitivity of 2 p.p.m. milk solids which permitted the evaluation of the circulation cleaning of a welded pipe-line circuit. Using a similar technique Merrill and Jensen (1962) examined the efficiency of detergency exhibited by tri-sodium orthophosphate with or without sodium hypochlorite, on milk protein soils.

Jennings, McKillop and Luick (1957) investigated the effectiveness of alkaline detergent constituents - soda ash (sodium carbonate) and sodium metasilicate - and a sequestering agent. By using laboratory and radioactive techniques, the effectiveness of these detergent constituents, both individually and collectively, were related to different degrees of turbulence and also different temperatures. It was shown that the effect of turbulence or temperature became less important as the physical and chemical effectiveness of the detergent increased.

Fortney, Baker and Bird (1955) made a study of cleaning stainless steel pipelines in place. They noted that the detergents used for this duty varied considerably in their composition, but that the majority were based on a mixture of an alkali, polyphosphate and a wetting agent. The use of chelated caustic was also examined. It was found that the detergent mixture which contained the highest concentration of polyphosphate gave the best physical cleanliness, assessed by bacteriological techniques. The chelated caustic also gave similar results.

Holland, Shaul, Thickes and Windle (1953) stated that cleaners with less than 10% wetting agent did not give satisfactory cleaning. On the other hand, Parker, Elliker, Nelson, Richardson and Wilster (1953) claimed that those with less than 10% wetting agent gave good cleaning. The results obtained by Fortney <u>et al</u> (1956) agreed with those of Parket <u>et al</u> (1953).

With the widespread use of detergent sterilisers in farm cleaning, the improved cleaning effect of the detergent, as a result of the added chlorine bearing compound, is of great importance. The addition of liquid sodium hypochlorite at the farm is a common practice. Where the chlorine bearing compound is incorporated in a proprietary detergent steriliser, an organic chlorine compound is used. Those most commonly utilised include dichlorodimethyl hydantoin, sodium *di*- and *tri*-chloro-isocyanurates. It has been shown by Cousins and MacKinnon (1962) that there is no change in efficiency of cleaning where a separate cleaning process has been followed by a sterilising process or where the two processes are simultaneous, as with a detergent steriliser. It is impracticable to use other methods of sterilisation such as steam or hot water, for the sterilisation of pipeline systems in view of the length of the pipelines and also the availability or economy of large quantities of steam or hot water.

The use of quaternary ammonium compounds cannot at present be considered in Scotland since they are not permitted by law and to date there are no preparations of iodophors which have been formulated and are suitable for circulation cleaning.

Holland *et al* (1953) indicated that when chlorinated alkaline cleaners are used for circulation cleaning, the chlorine acts both as a scrubbing and wetting agent and not only assists in the removal of the protein film, but also enhances the draining characteristics of the cleaning solution. It was shown that high concentrations of wetting agents produced heavy brown films in the line after a week. These films did not appear when chlorine was added to the alkaline solutions. When acid or alkaline detergent solution of quaternary ammonium compounds were used, brown films developed in the lines. Kaufmann and Tracy (1959) investigated the cause and method of removal of an irridescent discolouration in pipelines which were cleaned in-place. By examining the effect of different temperatures and circulating detergents, it was found that the use of a commercial non-ionic detergent at 120^{o}F resulted in the discolouration. An increase in the temperature did not assist in its removal, which could only be effected by the circulation of a chlorinated alkaline detergent.

Using methods of evaluation involving the use of gravimetric as well as radioactive techniques, Peters (1959) showed that chlorinated tri-sodium orthophosphate was more effective at 160°F than straight alkaline detergents, but that alkaline detergents were more effective at lower temperatures.

MacGregor, Elliker and Richardson (1954) investigated the effect of added sodium hypochlorite on detergent activity in circulation cleaning. It was pointed out that field observations had frequently substantiated the report that concentration of available chlorine in the range 25-100 p.p.m. aided the removal of soil from metal surfaces. Three different alkaline cleaners were used to remove a synthetic milkstone from strips of stainless steel which were subjected to a standard washing treatment, consisting of a preliminary wash with a1% organic acid, followed by a rinse and finally washing for 10 minutes in 1% (w/v) solution of detergent with different concentrations of sodium hypochlorite. Their results showed a marked increased in efficiency when the sodium hypochlorite was added. It was suggested that the improved efficiency in the presence of the sodium hypochlorite was due to an increase in the protein solubilisation. Wright (1936) found that the type of reaction depended on the pH. At low pH levels the available chlorine in the sodium hypochlorite was depressed by glycine, due to the formation of a chlorinated addition product, whilst at a high pH it was removed by the oxidation of the glycine. Similar effects were observed with similar nitrogenous compounds. Baker (1936) showed that comparatively small amount of protein degradation was brought about by a small amount of sodium hypochlorite. In the experiment 74.45 g. sodium hypochlorite rendered 33.78 of albumen non-precipitable by dodeca-tungstophosphoric acid, whilst the remaining 22.5 g of the sample were non-precipitable by trichloracetic acid. It is pointed out by MacGregor et al (1954) that since a relatively small amount of degradation may markedly increase protein solubility, the probable mechanisms of sodium hypochlorite subscription to cleaning is the degradation of the protein, resulting in the increased solubility and therefore more effective removal of milk deposits.

Kling and Lange (1960) postulated a theory that the potential energy of a soil particle as a function of the difference from the soiled surface is a result of the electrical repulsive energy and the van der Waal's attractive energy. The lowest energy state is provided by the adsorbed soil particle in a detergent free system. An important function of the detergent is to react with the adsorbed particle, in one way or another, and so reduce this energy level and so result in its removal from the soiled surface. Harris and Satanek (1961) have reviewed the energy and work relationship in cleaning operations and Bourne and Jennings (1961) discussed the necessity of energy to reverse the soiling process and remove the soil from the surface.

Somers (1949) lists the main constituents found in compounded detergents and discusses the desirable characteristics which each exhibits, and the factors involved in the formulation of detergents for specific cleaning duties. She points out that mixtures of two or more constituents in a compounded detergent often give greater efficiency than single chemicals because the desirable properties of each component are usually manifest in the resulting compound. There are several instances where different constituents materials of compounded detergents exhibit synergism.

Swartling (1959) listed the materials which are mostly used in the compounded detergents used for the cleaning of farm equipment and information on the composition of some detergent mixtures and cleaning compounds are given by Harding and Trebler (1957), McDowell (1941), Lindquist (1953) and Niven (1955).

McDowell (1942) stated that a correlation of the experience of different butter factory workers or research workers on proprietary mixtures is not possible without an accurate knowledge of the detergent composition and that research work on proprietary cleaners of undisclosed composition may be regarded very largely as a waste of time and effort. From the scientific viewpoint such results are almost worthless and from a practical point of view only of localised value.

Fortney et al (1955) stated that as the temperature of the detergent solution was raised the chemical activity of the detergent would be increased and that cleaning would be more efficient.

Fortney et al (1955) investigated different factors affecting the cleaning of stainless steel line without dismantling. The temperature of the circulating solution was controlled automatically by a solenoid operated steam valve. The alkaline detergent circulation was preceded by the circulation of a weak (0.016% w/v) solution of orthophosphoric acid. The circulation of one of the detergents - A - was carried out at two different ranges of temperature in order to assess whether these temperatures gave similar results. The two temperatures were, 120°F for 4 days; 140°F for 4 days and the results were compared with those obtained after circulation at 150°F. In all cases the time of circulation was for 20 minutes and the rate of circulation was 2 ft/sec.

It was found that the results obtained at the lower temperatures where the lines had been soiled with hot milk were unsatisfactory, the bacteriological condition being poor, whilst at the higher temperatures - 150-170°F - the same lines exhibited a more satisfactory bacteriological condition. Lines soiled with cold milk were found to be satisfactorily cleansed at the high and low temperatures of circulation. This part of the investigation was only carried out on the one detergent, so that no indication could be given as to the relationship between temperature and detergent composition.

Cleaning was carried out at the higher temperatures using four different proprietary detergents with the following composition:-

A

tri-sodium phosphate	60%
sodium *tri*-poly-phosphate	38%
non-ionic wetting agent	1%
organic chlorine bearing compound	1%

B

sodium carbonate	11.9%
sodium metasilicate	11.4%
sodium *tri*-poly-phosphate	66.4%
non-ionic wetting agent	1.3%
organic chlorine bearing compound	100%

C

sodium carbonate	56%
sodium meta silicate	34%
tetra-sodium pyro-phosphate	9%
organic chlorine bearing compound	1%

D

chelated caustic

composition not known

It was found that of the above cleaners, A, which contained the greatest proportion of phosphate in solution gave the best physical cleaning. A velocity of cleaning solution of 7 ft/sec at 130°F for 10 minutes showed better results on internal surfaces of cold milk lines than a velocity of 2 ft/sec at the same temperature.

It is pointed out that velocity is not related to the effectiveness of cleaning the bevels and gaskets where it appeared that temperature is more important. The method of connecting together fittings in America is more sophisticated than that found in the United Kingdom, where the connection is effected by simple rubber push-on sleeves. The gaskets and bevels result in a flush interior surface and this factor may well account for the satisfactory results which have been obtained by Fortney et al (1955); Holland et al (1953) and Parker et al (1953). These workers found that where the detergent is circulated at lower temperatures than those generally recommended in the United Kingdom, satisfactory bacteriological results can be achieved.

There are few reports comparing the relationship of the efficiency of cleaning with temperature and the composition of the detergent. Lindamood, Finnegan and Graff (1955) compared the efficiency of 6 detergents and detergent/sterilisers when used for circulation cleaning at different temperatures. The first series of circulation was carried out daily at a low temperature (105-140°F; 40°-60°C) for a period of 15 days. The investigation was then repeated with the same detergent or detergent/steriliser but at a higher temperature (130^{o}-160^{o}F; 54^{o}-71^{o}C) again for 15 days. The results indicated that there was more variation between the cleaning ability of the individual detergents than between a higher or lower circulation temperature with the same detergent.

In view of the contribution which chlorine bearing compounds have on the efficiency of cleaning, the results could have been confused by the use of the detergent steriliser. This would occur whether the evaluation was made by bacteriological techniques or whether a measurement was made of the residual soil.

EXPERIMENT

An investigation was made to relate the effect of the temperature of detergent circulation with that of the composition of the detergent.

Method

The commercial installation used was a 'round-the-shed' system of one double byre of stainless steel piping of approximately 290 ft. in length. The water was heated by means of an electric water heater. The pipeline was washed for two weeks using a detergent of known composition at a 'low' initial temperature (110-140°F; 43-60°C) and then at a 'high' temperature (140-170°F; 60-77°C) for a further two weeks. This sequence was then repeated using two other detergents also of known composition.

The pipeline was flushed clear of milk residues and drained. The detergent was made up in a rubber wash trough and circulated for 20 minutes. A cold water rinse for 5 minutes followed the detergent treatment.

Test rinses were taken of the pipeline by drawing from the most distant stallcock, a measured volume of sterile ¼ strength Ringer solution. It was found that 4 litres of this rinse were necessary to permit a reasonable volume to be collected in the receiver jar. Since the pipeline was U-shaped, 2 litres were drawn through from the most distant stallcock on each side. It was then pumped out from the jar, using the milk pump, through the milk delivery pipe to the sampling flask.

No preliminary sterilising or acid descaling treatment was carried out since the first detergent used in the trials was the normal cleaning compound used to clean this installation, nor was any additional treatment used on the rubber fittings. It was felt that any extreme variation in cleaning practice could seriously influence, if not invalidate, any results.

None of the detergents used contained a sterilant and none was added although under normal practice using these three compounds, sodium hypochlorite is added to make them detergent/sterilisers. Since the efficiency of cleaning was measured by determining the number of residual viable organisms from a sterile rinse drawn through the pipeline, such results would be adversely affected by any circulated sterilant. The higher circulation temperature would effect a measure of sterilisation per se but it would be impossible other than perhaps by using radioactive techniques to separate any improved cleaning as a result of the increased temperatures from any bactericidal effect of the circulating detergent solution at the higher temperature.

The apparent physical cleanliness of the pipeline did not change either as a result of the increased temperatures or with different detergents.

In addition to determining the total count of the rinse, the composition of the bacterial flora was investigated using certain differential media such as

Rogosa agar, Mannitol salt agar, violet red bile agar. A count was also made of the Gram negative organisms by plating the rinse on standard Yeastrol milk agar to which was added, immediately before pouring the plate, 1% of a 0.05% (w/v) crystal violet solution (Holding, 1954). Thermoduric and spore counts were determined by inoculating 8 ml of sterile separated milk with 2 ml of the rinse heated to 65°C for 30 minutes or 80°C for 20 minutes respectively. Milk souring organisms were determined by inoculating litmus milk with 1 and 2 ml of the rinse. Presumptive coliforms were determined by MacConkey Bile Broth.

The three detergents used were of the following approximate composition:-

A		B	
sodium metasilicate	35%	sodium metasilicate	40%
tri-sodium ortho phosphate	55%	sodium carbonate (anhydrous)	40%
sodium tri-polyphosphate	9%	sodium metaphosphate	20%
non ionic detergent	1%		

C	
sodium metaphosphate	20%
sodium carbonate (anhydrous)	80%

All these detergents were used at a concentration of 0.25% (w/v).

Results

The results are given in the following tables.

Table 1. <u>The bacterial count of rinses of milking pipelines after different cleaning treatments determined by colony counts on various media</u>

DETERGENT A

Temperature	Total count x 10^3	Milk souring organisms	Rogosa agar x 10^3	Mannitol salt agar	Violet red bile agar	Gram -ve count	Spore count	Thermoduric count	Coliform
more than 140°F	2,208		151	8,120		1,200	102,000	91,280	
	6,336	+	630	294	70	6,100	10,000	91,300	1 ml
	3,168		111	4,500		2,400	92,800	88,100	
	4,740		155	3,790		1,200	101,000	72,250	
	6,240	+	241	1,348	13	270	127,000	36,400	
	2,208		121	2,400		1,420	131,000	87,000	
	4,080		174	274		1,210	95,000	68,000	
	5,460		151	0	63	610	60,000	13,200	2 ml
	3,000		142	3,100		1,080	34,000	53,000	
	3,900		194	0		400	120,000	45,000	
Average:	4,134	20%	207	2,380	14	1,710	171,000	69,500	20%
120-140°F	3,280		257	800		3,100	1,700	14,100	
	5,040	+	198	570		2,200	1,100	15,300	
	4,020		301	340		3,108	1,210	15,500	
	6,000	+	114	144		2,410	970	13,370	
	8,040	+	102	144		1,900	0	9,100	
	8,700	+	271	109		980	900	8,600	
	9,780	+	263	341		550	0	7,700	
	1,056		167	800		340	300	5,500	
	8,100	+	151	600		580	30	6,900	
	10,064	+	191	120		1,410	0	10,200	
Average:	6,207	70%	202	397		1,640	620	10,630	

Table 1. The bacterial count of rinses of milking pipelines after different cleaning treatments determined by colony counts on various media

DETERGENT B

Temperature	Total count x 10^3	Milk souring organisms	Rogosa agar x 10^3	Mannitol salt agar	Violet red bile agar	Gram -ve count	Spore count	Thermoduric count	Coliform
More than 140°F	5,280		98	240		1,780	5,800	21,900	
	680		54	312		2,940	4,800	38,400	
	7,440	+	175	390		1,340	17,400	84,700	
	8,627		154	270	100	4,980	1,200	1,800	
	5,040	+	161	210		2,380	14,700	16,400	
	3,720		201	860	70	5,180	1,800	15,300	
	5,800		355	1,620	40	3,120	2,300	14,700	
	6,840		162	280		3,060	7,500	21,300	
	7,800	+	184	490		4,100	9,600	21,000	
	3,480		134	984		3,780	9,800	17,000	
Average:	4,466	30%	168	570	21	3,270	7,090	26,450	
120-140°F	8,646	+	151	140		2,140	190	13,700	
	8,040		134	840		5,710	130	21,300	
	12,520	+	97	580		3,470	470	14,900	
	14,720	+	64	580		4,000	980	24,300	
	6,360		123	210	20	1,360	0	13,700	
	7,880	+	97	180		2,140	20	8,400	
	7,200		84	190	100	1,470	600	6,800	
	6,720		145	1,200		4,420	0	16,200	
	7,440		148	810		1,560	50	9,800	
	5,160		129	460	20	3,940	0	2,820	
Average:	8,439	40%	117	510	14	3,020	250	13,100	

Table 1. The bacterial count of rinses of milking pipelines after different cleaning treatments determined by colony counts on various media

DETERGENT C

Temperature	Total count $\times 10^3$	Milk souring organisms	Rogosa agar $\times 10^3$	Mannitol salt agar	Violet red bile agar	Gram -ve count	Spore count	Thermoduric count	Coli-form
More than 140°F	4,840		147	530		1,470	200	5,800	
	7,810		139	470		2,210	340	14,800	
	9,310	+	18	490	30	1,800	0	16,700	
	8,750	+	117	610		1,210	430	8,700	
	9,470		143	530	100	1,470	670	14,300	
	4,970		127	170		1,600	100	7,400	
	8,910	+	99	210	40	3,840	940	3,000	
	8,760		101	890	10	2,700	180	5,600	
	6,430		74	740		1,060	770	17,400	
	8,130		83	390	30	1,230	0	13,100	
Average:	7,740	30%	104	503	20	1,860	355	10,600	
120-140°F	9,700		11	730		1,740	110	16,100	
	11,400	+	7	610		2,370	70	13,700	
	13,700	+	6	890	20	2,140	0	9,800	
	8,400		19	760		1,750	30	15,400	
	15,400	+	13	950	100	3,900	310	8,300	
	11,740	+	10	850		4,410	190	9,100	
	9,460	+	11	630	30	3,970	240	8,900	
	8,390		7	760		2,740	80	7,400	
	5,940		13	870	100	3,150	100	11,100	
	19,460	+	10	530	20	3,810	70	8,100	
Average	11,600	60%	106	760	30	3,000	120	11,000	

Table 2. The effect of the temperatures of circulating detergents on the bacterial flora of rinses of pipelines as determined by colony counts of rinses on various media.

Detergent	A		B		C	
Temperature Range	More than 140°F	120-140°F	More than 140°F	120-140°F	More than 140°F	120-140°F
Total count/ml	4,134,000	6,207,000	4,466,000	8,339,000	7,740,000	1,160,000
Milk souring organisms	20%	70%	30%	40%	30%	60%
Rogosa agar	207,000	201,500	168,000	1,172,000	104,000	106,000
Mannitol Salt Agar	2,380	397	570	510	503	760
Violet red bile agar	14		21	14	20	30
Gram -ve organisms	1,710	1,640	3,270	3,020	1,860	3,000
Spore Count	171,000	620	7,090	250	355	120
Thermoduric Count	69,500	10,600	26,450	13,100	10,600	11,000
Coliforms	20%	-	-	-	-	-

Discussion

The apparent physical cleanliness of the pipeline did not change either as a result of the increased temperature or with different detergents. By examination of the total colony count for the high temperature range, $4,130 \times 10^3$, the counts ranging from $2,208 \times 10^3$ - $6,336 \times 10^3$. Detergent B, whilst the average total colony count was similar to A, being $4,466 \times 10^3$, the range was much wider 680 - 8,627. Detergent C was much higher.

A similar pattern emerges from the results of the rinses from the lower temperature range, A apparently giving the more satisfactory results. A was the most complex of the three detergents used, containing four different constituents, B three and C only two constituents. From this investigation, whilst limited in extent, it would appear that a detergent composed of basic constituents is not so effective as a more sophisticated detergent which is formulated for the particular duty.

In all instances the colony count on Rogosa agar (30°C for 5 days, Sharpe, 1960) indicated that lactobacilli were the dominant group of organisms. Except for detergent C, an increase in the temperature of circulation was reflected in a reduction of the Rogosa count.

The count on Mannitol salt agar was within the same range except when detergent A was circulated at the high temperature range. It was subsequently found that a severe outbreak of mastitis occurred during this period and it was assumed that it responded to medication.

The colony count using violet red bile agar was very low - extremely low in view of the magnitude of the total colony count on Yeastrel milk agar - and this is reflected also in the absence of coliform organisms. Only on two occasions during the 12 weeks investigation were coliforms found in the rinse of the equipment. This was in the complete absence of any chemical sterilisation since detergents only were used for the trial. A subsequent treatment with a sterilising rinse was made only after the rinse had been taken in order to bring the installation up to an acceptable bacteriological standard. In both cases where coliforms were present, the detergent used was A and, in a now contrary manner, occurred during the high temperature circulation.

The spore count was higher in the rinses taken after high temperature circulation, especially so in the case of detergent A where the increase from the low temperature circulation was nearly x 300 - 296.6 - whereas with detergents

B and C the increase was 28.3 and 3 respectively.

The thermoduric count was most variable from day to day and, for detergents A and B, the average count was lower during the lower temperature circulation than the higher. This variation was not reflected with the detergent C where the average thermoduric count was the same.

Milk souring organisms were found in many of the rinses irrespective of the temperature, but their incidence was greater at the lower range. Detergent B did not exhibit much difference with milk souring organisms, between the high and low temperature circulations. Griffiths and Thomas (1959) suggest that milk souring organisms are a useful index for the assessment of milk quality and these results would underline this suggestion.

Conclusions

The results indicated that not only is there a change in total colony count as a result of a higher temperature of circulating solution, as would be expected, but that a change in detergent composition results in a change of total count. The difference between the effectiveness of cleaning by 3 detergents of different composition, determined by the residual bacterial count was greater than the difference by either a higher (140-170°F) or lower (110-140°F) temperature. This agrees with the findings of Lindamood *et al.* (1955).

The composition of bacterial flora, determined by the use of selective media, appeared to be affected not only by the change in temperature of the circulating detergent, but also to a lesser degree, by a change in detergent composition.

TEMPERATURE LOSSES THROUGH PIPELINES

During the circulation of the cleaning solution through a pipeline circuit at an elevated temperature, there will always be a loss of heat from the circulating solution to the surroundings. The rate and extent of such a loss would vary with several factors. These would include the temperature differential between the ambient and the solution temperatures - any loss would be greater in the colder months of the year, when the temperature difference would be greater; the length of the pipeline; the rate of flow of the solution; the conducting characteristics of the material from which the pipeline is constructed; thickness of the pipe wall; and the diameter of the pipeline and the volume of solution in circulation.

Although there are many reports concerning the cleanability of different finishes of stainless steel, and also comparisons between the relative cleanability of stainless steel or glass, little attention appears to have been paid to the loss of heat from the circulating solution from pipes made of different materials. Scheib (1960a) reported on some studies made in conjunction with the New York State and Dairy & Food Sanitarians' Association. Scheib gave the following results:-

circulation time mins.	A		B		C		D	
	Tank Temp. °F	Return Temp. °F	Tank Temp. °F	Return Temp. °F	Tank Temp. °F	Return Temp. °F	Tank Temp. °F	Return Temp. °F
Start	152		143		143		142	
1	133	126	142		142		141	
2	128	123	126	102	138	92	124	102
3	126	122	120	114	126	116	120	117
4	124	120	118	114	123	117	124	128
5	121	118	117	113	121	115	124	122
6	119	116	115	112	119	114	120	117
7	117	114	114	109	118	110	118	117
8	115	113	112	108	117	110	118	116
9	113	111	111	107	115	109	116	115
10	112	109	110	106	114	107	115	114
15			102	100	105	100	111	110
20			98	93	100	96		

A was a parlour with a comparatively short glass line; B was a similar installation but with the inclusion of large interceptor glass jars in the parlour; C was a 'round-the-shed' installation with 270 ft. of glass line; D was a 'round-the-shed' installation with 300 ft. of stainless steel line.

The readings were taken in February, except in D when the readings were obtained in September. It is noted that there was little variation in temperature as a result of seasonal variation, but it is pointed out that none of the lines were exposed to the outside of the buildings.

No firm conclusions were drawn from these results.

EXPERIMENT

It was considered that heat loss could be an important contributory factor in the efficiency of circulation cleaning and a study was made of, firstly, the rate of heat loss during circulation cleaning and, secondly the rate of heat loss from pipelines of different materials.

1. Rate of heat loss

Method

In parallel with an investigation relating temperature with detergent composition, readings were taken of the temperature of the circulating detergent at the inlet and outlet of a pipeline system. The installation being used was a 'round-the-shed' system comprising 190 ft. of stainless steel piping with an interceptor jar giving a total surface area of 67 square feet. The inlet temperature was taken by means of a bi-metallic dial thermometer (Table 1) (Messrs. British Rototherm Ltd., London) and the outlet temperature was measured directly by a mercury in glass thermometer.

Results

The readings obtained are given in Table 3.

Table 3. <u>Temperature loss of circulating solutions in a stainless steel pipeline system</u>

Circulation time in Min.	Temperature °F											
	In-let	Out-let	In-let	Out-let	In-let	Out-let	In-let	Out-let	In-let	Out-let	In-let	Out-let
0	137		170		127		168	95	167		171	
2	133		165		123	66	165	100	156		162	
4	118	64	149	62	116	70	155	103	149	67	157	50
6	114	79	137	85	113	75	147	105	134	83	146	64
8	110	84	132	94	111	80	145	108	127	93	143	96
10	106	85	125	94	108	78	138	107	122	94	137	92
12	102	85	119	94	103	76	135	106	119	93	134	91
14	100	83	114	91	101	74	125	103	115	92	130	90
16	97	82	109	89	101	73	118	100	112	90	125	88
18	95	79	107	87	100	73	116	98	109	88	123	86
20	93	77	106	85	98	71	115	96	108	88	121	85

Where no reading is given, the temperature was equal to the ambient.

Readings were taken in ^{o}F since this is the usual system of temperature measurement for circulation cleaning, under commercial conditions.

Discussion

Each of the results in Table 3 are the arithmetic average of the readings taken during 10 consecutive circulations. It can be seen that the maximum temperature of the circulating solution, as shown by the highest temperature of the returning liquid, was achieved between 8 and 10 minutes after the beginning of the circulation. This time is related to the length of the pipeline, the initial temperature of the solution only affecting the highest temperature achieved, since the initial temperature varied from one series of readings from between 110-140^{o}F. It is apparent that the shorter the length of the pipeline the shorter the length of time before the maximum temperature is achieved. By studying the results obtained by Scheib given above it can be seen that the shortest time for the outlet temperature to reach its maximum is A and the longest is D these being the shortest and longest length of pipelines respectively.

This would have an effect on the efficiency of the cleaning of the detergent since the time of circulation after the system had achieved the maximum temperature could be insufficient. It is therefore, good practice to shorten this period of time by flushing the system with hot water prior to the detergent circulation, and allowing it to run to waste. This treatment brings up the temperature of the pipeline and also limits the loss of heat by the initial circulation of the detergent. This is generally recommended, but in hard water areas to prevent the deposition of hard water scale, the first quantity of detergent is allowed to run to waste, thus achieving the same result.

2. Heat loss in relation to different materials

Since the loss of heat depends, amongst other factors, on the material of construction of the pipeline, an attempt was made to determine the effect of different materials on the heat loss of the circulating solution.

Method

Readings were taken to determine the magnitude of the loss in temperature from a solution circulating in pipes of different materials. Lengths of pipe of different materials were connected together by rubber sleeves as used in farm installations and made into a part of a pipeline circuit of approximately 83 ft in length. The circuit was so arranged that hot water was circulated through the system and the temperature of the water taken every 30 seconds during the 20 minutes circulation. Twenty minutes was selected as the duration of the study since it is the usual time of circulation of the cleaning solution on farms practicing circulation cleaning. At the same time, the temperature of the external surface of the different sections of pipes was measured by means of a bi-metallic dial thermometer clamped to the outside of the pipes. In order to eliminate any possible error which could be due to the inaccuracies of the thermometers, they were inter-changed from one pipe to another between series of readings, as were the relative positions of the pipes of different materials. The materials examined were (a) stainless steel 18:8, 1¼ in (3.7 mm) outside diameter x 1.2 mm wall; (b) glass, 1¼ in (31.7 mm) outside diameter x 3.0 mm wall; (c) styrene acrylonitrile, supplied by Messrs. BX Plastics, Manningtree, Essex; (d) 'Polyorc' alkathene polythene supplied by Messrs. Yorkshire Imperial Metals Ltd., Leeds; (e) 'Plastronga' polythene, supplied by Messrs. Yorkshire Imperial Metals Ltd., Leeds; (f) 'Lamtix' epoxy resin glass fibre supplied by Messrs. Tredigan Ltd., Cumbernauld, Glasgow.

When comparisons were carried out with the latter four materials, it was found that, insofar as their heat conductance was concerned, there was practically no difference between them. They are therefore, collectively referred to as 'plastics' in the results of the investigation.

The investigation was carried out with hot water, which was drawn from a tank through the pipeline by a standard Alfa-Laval vacuum pump, and collected in a glass receiver jar from which it was returned to the tank by a centrifugal pump, all the equipment being of a design used in normal milking installations. The temperature of the circulating water used in different measurements varied between 147°F and 190°F and 23 series of temperature measurements were carried out. (Plate 4 & 5).

Results

It was noted that the results fell into four groups of readings, each at a different ambient temperature. The number of readings taken were

4	at	an	ambient	temperature of	62°F
7	"	"	"	"	70°F
8	"	"	"	"	72°F
4	"	"	"	"	81°F

The results are given in Table 4.

Table 4. Temperature loss of circulating solutions in pipelines of different materials

Time of circulation min.	ambient temp. 81 °F Temperature °F				ambient temp. 72 °F Temperature °F				ambient temp. 70 °F Temperature °F				ambient temp. 62 °F Temperature °F			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1	184	96	78	60	186	90	54	43	153	91	72	67	153	85	69	53
2	174	145	100	51	167	135	80	58	142	110	88	75	140	108	79	63
3	173	154	111	69	167	148	97	60	142	121	104	82	138	110	86	68
4	173	165	119	74	164	149	104	81	143	125	105	87	138	115	91	73
5	170	165	123	88	162	152	115	98	142	127	111	91	137	118	97	78
6	169	166	126	93	161	158	123	101	141	129	111	97	135	120	103	79
7	167	167	127	95	158	157	123	105	140	129	113	96	134	124	107	81
8	165	165	128	98	156	155	125	106	140	129	113	98	134	125	108	84
9	165	165	128	101	155	155	126	109	139	129	114	99	134	124	108	85
10	163	165	128	102	154	154	126	110	138	129	114	99	132	124	106	85
11	161	161	129	102	153	152	126	110	137	128	114	100	132	124	107	85
12	160	160	129	103	152	151	126	111	136	128	114	100	132	123	107	86
13	159	159	127	103	150	150	127	111	136	127	116	100	131	123	107	86
14	158	158	126	103	148	148	126	111	135	127	116	100	131	122	106	86
15	159	156	126	103	147	147	126	111	134	127	116	100	130	121	106	86
16	155	155	125	103	145	145	126	111	133	127	114	100	129	121	105	86
17	154	154	123	103	145	145	126	111	132	126	113	100	129	120	104	86
18	153	154	122	103	145	144	125	111	132	125	112	98	128	120	104	86
19	152	152	121	103	144	143	124	111	131	124	112	98	128	119	104	86
20	152	152	121	104	144	142	124	110	131	124	112	98	126	118	104	86

1 - Temperature of circulating water.
2 - External temperature of stainless steel pipe
3 - External temperature of glass pipe.
4 - External temperature of plastic pipe.

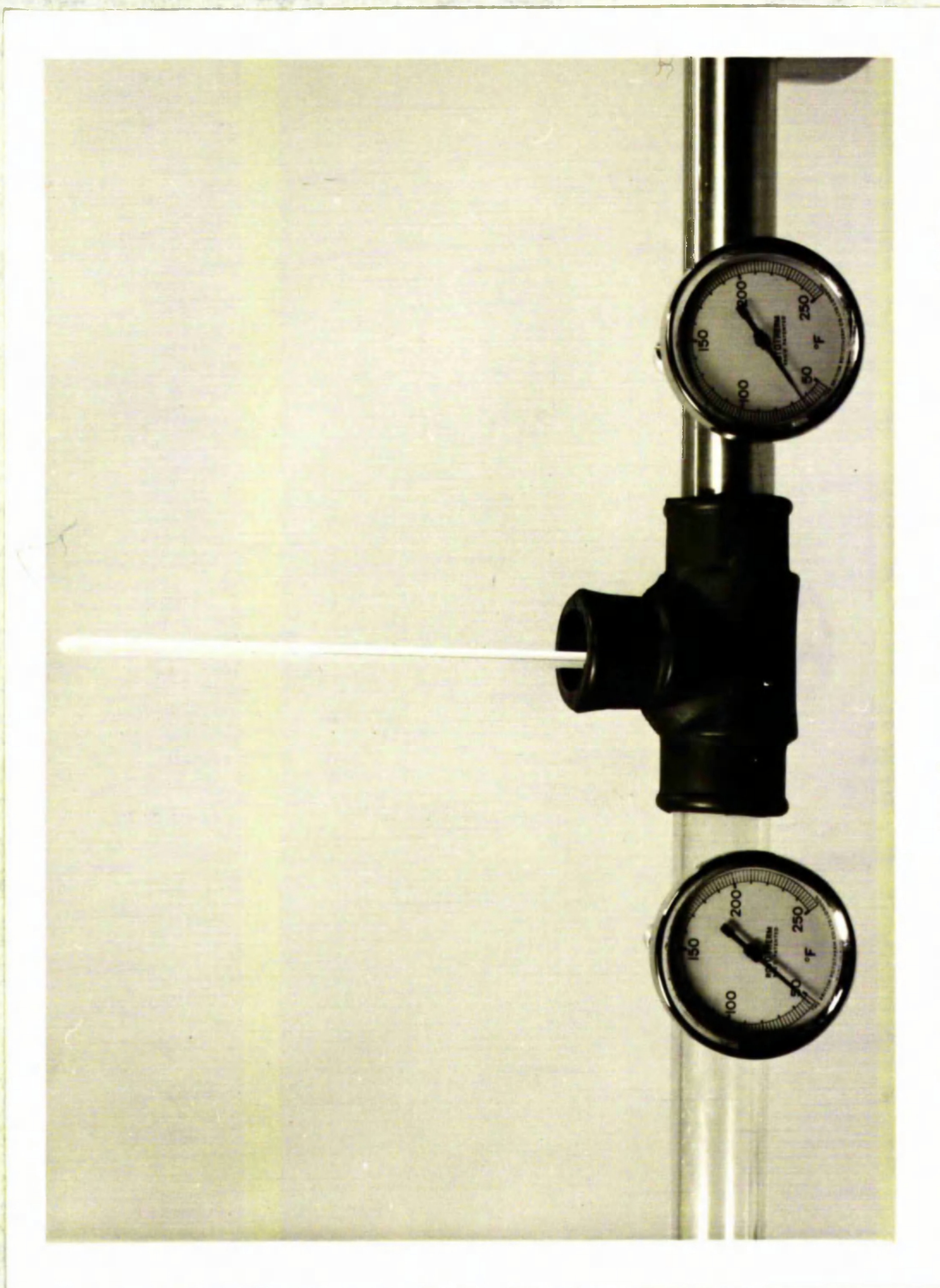

PLATE 4.

Measurement of the relationship between the temperature of circulating liquid and the external temperature of pipelines of glass or stainless steel.

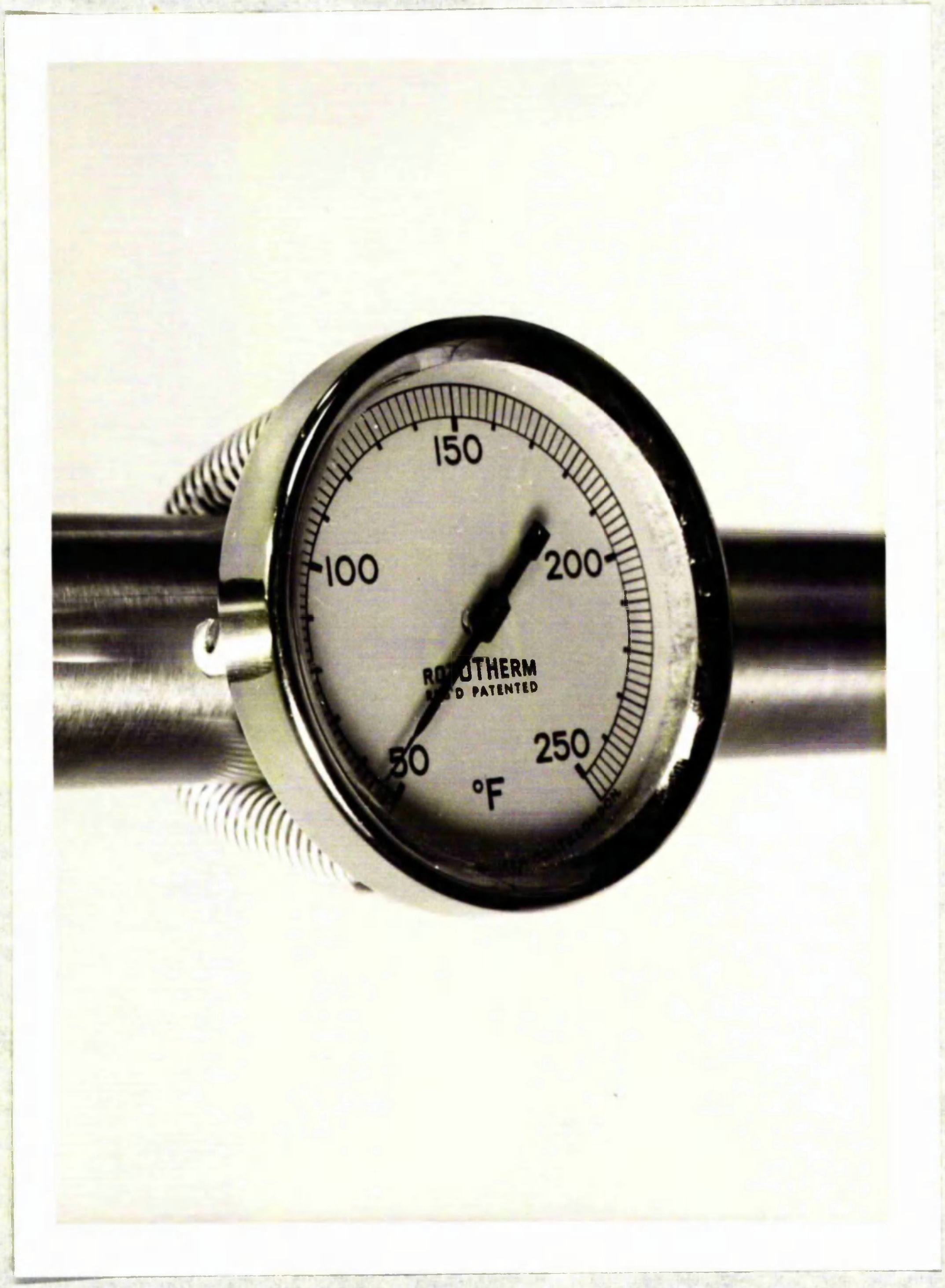

PLATE 5.

Pipe thermometer to measure external temperature

Discussion

It was noted that the external temperature of the stainless steel rapidly rose to a temperature approaching that of the circulating water, and the maximum temperature was achieved in between 4 and 7 minutes of circulation beginning and this maximum temperature was a mean of only 4.5^{o}F below that of the circulating water. From then on, during the circulation, the gradients of these two temperatures followed the same curve and in some particular circulations were identical.

With glass lines, however, the highest temperature was not reached until the circulation had continued for 8 minutes and even then it but rarely approached within 20^{o}F of the temperature of the water. The temperature of the external surface of the glass did not rise significantly once the initial temperature had been achieved, but it differed markedly from the results with the stainless steel pipe, in that it retained the heat considerably longer once the circulation of the water had ceased.

With the 'plastic' types of pipe, the external temperature rose at a slower rate than either the glass or stainless steel. The highest temperatures were not reached until 10 minutes after the commencement of the circulation and the difference between this recorded temperature and that of the circulating water was more than 30^{o}F.

By relating the difference in temperature between the circulating water and the pipelines of the materials under investigation with the ambient temperatures, it can be seen that, with higher ambient temperatures, the temperatures attained by the pipelines do not approach so nearly to that of the circulating water. This, however, was not found with the 'plastic' pipes where the reverse was the case. Scheib (1966b) found that there was little variation in temperature loss due to seasonal i.e. ambient, temperatures. In his investigations, however, none of the lines were exposed to the outside, whereas many installations in South West Scotland not only have extremely long pipelines, but also lengths are outside the buildings and exposed to low seasonal temperatures.

In order to assist in the retention of the heat of the circulating solution, it would be preferable to use pipelines constructed of suitable materials which lost the least heat to the atmosphere. Although at first sight it would appear that glass lines would be more suitable than stainless steel, in that less heat would be lost during the circulation due to lower conductance, the results of the investigation do not confirm this assumption. In the factors involved in heat lost from the circulating solution, one additional factor is the amount of heat absorbed by the pipeline itself. Whilst the temperature rise of the pipeline is less for glass than for stainless steel, the specific heat of glass being 0.174 + 0.00036t at temperature t°C, which is greater than that of stainless steel which is 0.12. The weight of glass in the system is also more than that of stainless steel being approximately 3% greater.

The loss of heat from the circulating solution to the pipeline takes place in two ways. Firstly, heat would be absorbed by the pipeline, until, theoretically, it was at the same temperature as the solution. This condition would not be often achieved, however, since at the same time the pipeline would be losing heat to the atmosphere by conduction. Hence not only would the specific heat and conductivity characteristics of the pipeline material be of importance but also the mass of the material in the pipeline.

The weight per unit length of a glass pipeline is 3% greater than that of stainless steel so that the loss of heat by the circulating solution in warming up a glass pipeline would be a little greater than that lost by conduction by a corresponding stainless steel pipeline. Where the pipeline is long, the loss by conduction would be greater than that required to heat the pipe so that under these conditions it would be preferable to use glass pipelines. No exact value can be given for this length, however, since other factors such as ambient temperature, length exposed outside and the rate of flow would cause great variations. It would seem that where longer runs of pipeline are used, particularly where lengths are exposed to outside temperatures, glass would be the better material but for shorter lengths of pipe-line such as milk parlours, stainless steel would be better since there would be less heat absorbed by the system than would be lost to the atmosphere.

In the instances quoted, the glass is taking up more heat than the stainless steel, although the latter loses less heat to the atmosphere. This would account for the apparent anomalous result. It follows, therefore, that the more suitable material for a pipeline would depend on the conditions.

The group of plastic materials examined were more efficient in heat retention but these materials are not yet suitable for the construction of milk pipelines, either because of the distortion, which can occur at temperatures often achieved in cleaning, or the absence of tests confirming their suitability.

The results of this investigation agree with that of Scheib (1966b) who stated that limited studies showed that the temperature was maintained a little better with stainless steel than with glass.

Scheib (1966b) also reports on the temperature loss of circulating solution of two pipeline systems one of stainless steel and the other of glass. The two pipelines were approximately 300 ft and 270 ft respectively, both systems being installed within the byre and both being washed with 10-20 gallons of solution. Temperature readings were taken at one minute intervals, both in the wash tank and in the discharge end of the pipe leading back into the tank. The results are given in Table 5.

Table 5. Temperature loss of circulating solutions through pipelines of stainless steel or glass

circulation time in minutes	Stainless steel installation		Glass installation	
	Temp. in Wash Tank °F	Temp. of water at discharge °F	Temp. in Wash Tank °F	Temp. of water at discharge °F
Start	142		143	
1	141		142	
2	124	102	138	92
3	120	117	126	116
4	120	120	123	112
5	124	122	121	115
6	124	117	119	114
7	120	117	118	110
8	118	116	117	110
9	118	115	115	109
10	116	114	114	107
11	115	113	113	106
12	113	111	109	105
13	112	111	108	104
14	111	110	107	102
			105	100

(Scheib, 1966b)

Since the initial temperatures of both solutions were $142^{O}F$ and $143^{O}F$ the two systems could be assumed to be under similar conditions, and although no indication was given of the ambient temperature, it is understood that the readings were taken about the same time.

It can be seen that the maximum temperature of the returning solution was reached at the same time - 4 minutes after the beginning of the circulation. That the temperature of the returning solution at the end of the circulation is lower for glass than that for stainless steel supports the contention that with installations of this size the loss of heat to the atmosphere by the stainless steel pipes is less than the amount of heat absorbed by the glass line from the solution.

It must be pointed out, however, that whilst the temperature of the outside of the glass pipe is lower, the milk-contacting surface would be at the temperature of the circulating liquid. It is therefore prossible to reach bactericidal temperature on the inside whilst lower temperatures were being recorded on the outside of the pipe.

This characteristic of the conduction of heat by the different materials is particularly important in 'round-the-shed' installations in assisting to maintain the temperature of the circulants. Not only would economies be effected in heat, but lower temperatures would adversely affect the cleaning efficiency of the detergent solution in the more distant sections of the pipe, but also, where the temperature used contributes to the sterilisation of the circuit, lower temperatures would place a greater burden on the action of any chemical bactericides used.

This aspect is also of importance in advisory or investigational work where the measurement of the maximum temperatures achieved during cleaning are measured by paper thermometers (Thermopaper paper thermometers supplied by Wenz & Cie., 15 Copthall Street, London, E.C.3.). These indicating strips of paper are attached to the outside of the equipment by transparent adhesive tape. When a specified temperature has been reached, the indicating strip turns black. These indicating strips, when taped on to equipment, would give an incorrect result, since the temperature recorded, except in the case of stainless steel equipment, would be considerably lower than the correct temperature of the circulating solution. Since with glass equipment, this error would be in the region of 20°F, this could result in false conclusions being drawn. (see Plates 6 & 7).

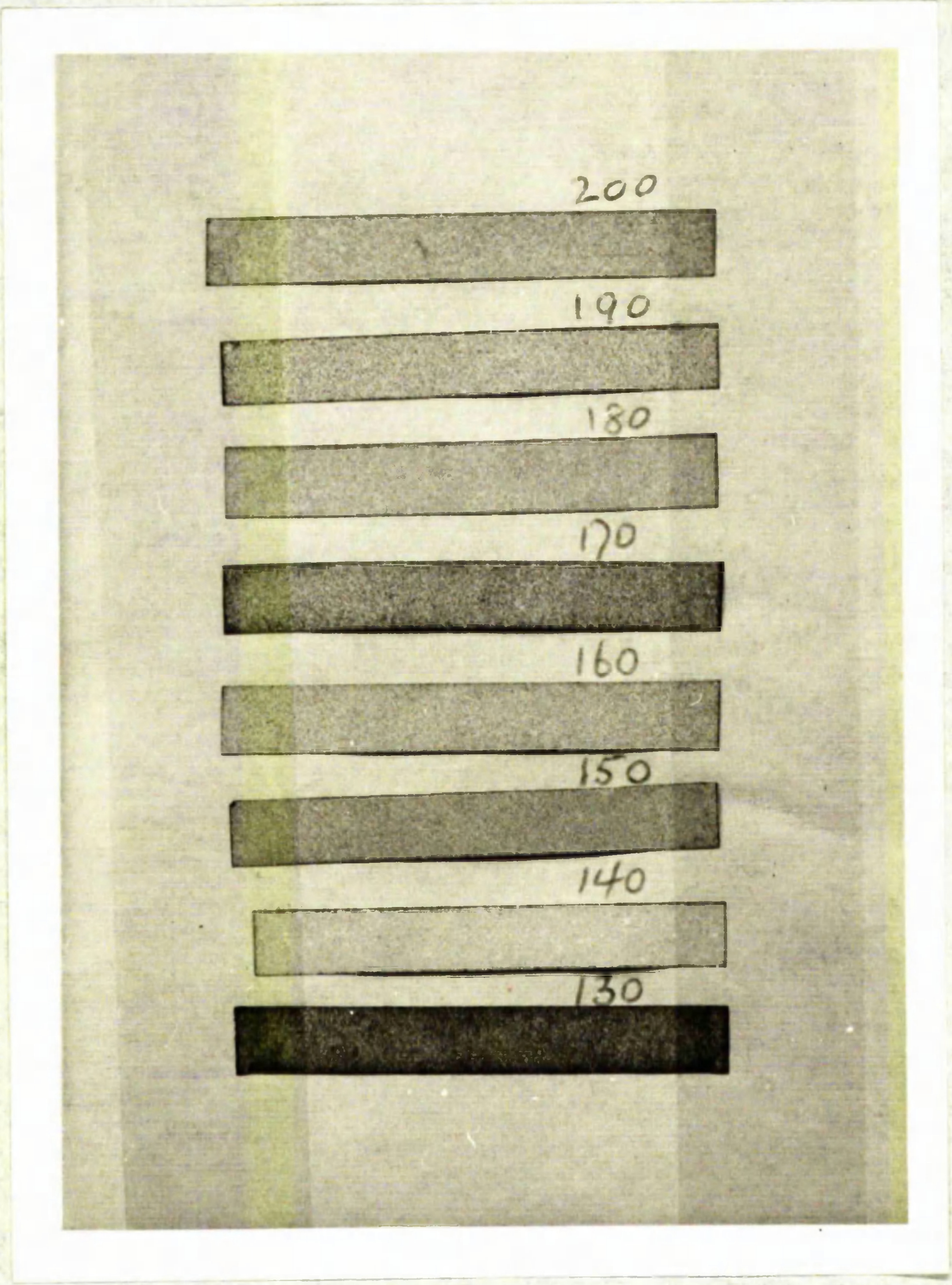

PLATE 6.

Heat sensitive strips of paper used to indicate maximum temperature attained during circulation.

(a) before circulation.

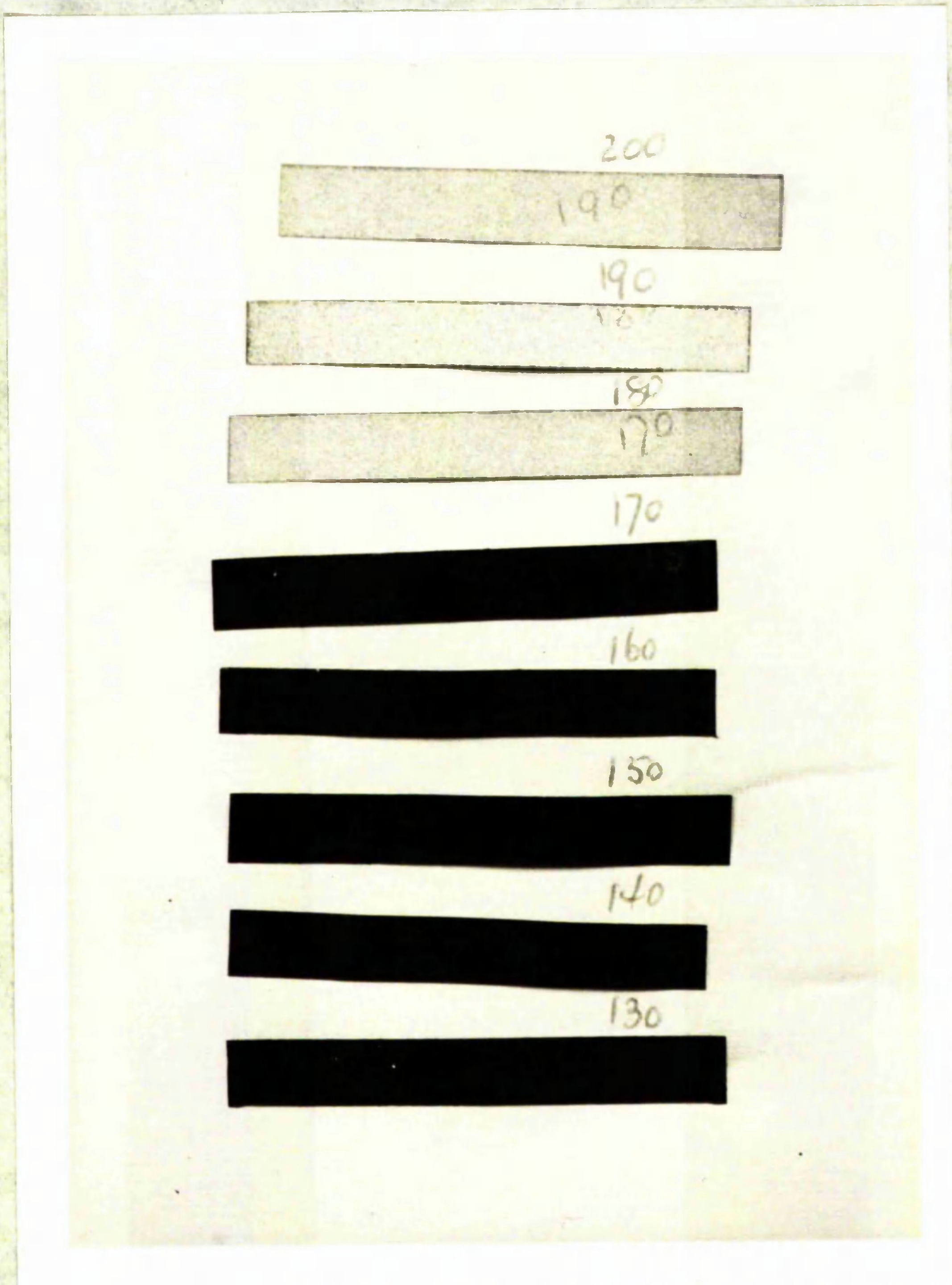

PLATE 7.

Heat sensitive strips of paper used to indicate maximum temperature attained during circulation.

(b) after circulation

Conclusions

A study was made of the loss of heat from pipelines by circulating solutions at elevated temperatures. It was found that with the same pipeline, the time taken for the returning solution to attain its maximum temperature was approximately the same length of time, the initial temperature only affecting the highest temperature achieved.

The relative loss of heat to the atmosphere, as measured by the external temperature of the pipeline, of pipes made of stainless steel was compared with those of glass or different plastic materials. It was found that, by taking 23 different series of readings with circulating temperatures between 147 and 190°F, with higher ambient temperatures, the temperatures do not approach so nearly to that of the water.

It is pointed out that, whilst glass has a lower conductivity than stainless steel, its heat capacity is greater and it would therefore absorb much more heat than would have been dissipated to the atmosphere by the stainless steel. The results obtained show that stainless steel is preferable for milking parlours and other installations which use short length of pipelines. For longer pipelines and especially where the pipeline is exposed to winter ambient temperatures, glass has been shown to be preferable.

BACTERIAL FLORA OF PIPELINES

Freshly drawn milk from a healthy cow contains only a few bacteria, probably very largely consisting of micrococci which are generally admitted to have little effect on the keeping quality of the milk or its suitability for the manufacture of dairy products.

Different udder infections which give rise to abnormal milks can result in other types of organisms such as streptococci, staphylococci, or coliform bacilli being secreted with the milk. Pette (1961) stated that the first object in hygienic milk production was to cure the cattle diseases which are also pathogenic to humans or which cause economic loss. For this reason tuberculosis and brucellosis have received much attention and have in many dairying countries been, or are in the process of being, eradicated. These two diseases are of importance for medical reasons. The same cannot be said of mastitis which is of considerable importance in milk production. Mastitis causes economic loss by a diminution of the quantity of milk produced and in some cases affects the proportion of the milk in such a way that, from a hygienic and aesthetic point of view, the milk should not be used.

Under normal commercial conditions, however, the milk is contaminated with bacterial from different sources and many of these effect the milk or milk products which may be manufactured from it. Sources of bacterial infection, other than the original microflora have been listed by Clegg (1957) who indicated three possible sources - the exterior of the udder, equipment, and other extraneous contamination. Air bourne contamination will be extremely small and in the majority of installations the milk is out of contact with the atmosphere until it has been discharged from the releaser jar in the milk cooling room. Petts (1962) stated that even gross contamination by dung or fodder will not greatly increase the total number of bacteria in the milk, although Thomas, Druce and Davies (1966b) found that cow manure contained large numbers of bacteria which were capable of growing at low temperature.

Clegg (1957) stated that contamination from equipment is by far the most important and therefore the most critical factor in hygienic milk production, could be the condition of the milk handling surfaces. Imperfectly cleaned surfaces permit micro-organisms to proliferate between milkings and in certain instances the contact of milk and such a surface is sufficient to lower the quality of the milk to a point where it is not acceptable to the buyer. Patte (1963) emphasises the importance of the cow and its environment - the dung, fodder and the milking equipment - in the production of hygienic milk. Thus contamination by numerous saprophylic species - faecal streptococci, betacocci, aerobic and anaerobic sporeformers, coliforms, streptococci pseudomonds and sometimes thermoduric organisms - can occur.

If the equipment is rendered sterile before the milk comes into contact with it, the milk will be of satisfactory bacteriological standard even if inadequately cooled. Prompt cooling of the milk limits the bacterial growth and it has been stated (Patte, 1961) that the apparent improvement of the bacteriological quality of milk in recent years is the result of the better cooling facilities which are now more general on the farm, rather than the result of improved methods of production. The first essential step in milk production is to prevent the infection of the milk and limit as far as possible contaminating bacteria. Nakanashi and Yutaka (1962) reported on the bacterial flora of the udder, the milking pail and milk from the milk can. They found that the initial flora of the milk from the udder contained only a small number of bacteria, and that the most common type was staphylococci. A comparison of freshly drawn milk with that from the milking bucket and that from the can indicated that the contamination of the milk from external sources may be serious and of these sources, equipment was by far the most important.

On the other hand, Carriere et al. (1955) found that the udder was the main source of micro-organisms in the milk. Satisfactorily cleaned milking equipment contributed little to the total count. The investigation however, was made under carefully controlled conditions and since the milking equipment - direct to can equipment - had been carefully and efficiently sterilised, the results cannot be considered as representative of results which would be obtained under commercial conditions.

Thom (1962) found that unsterile equipment was either wholly or partly responsible for 66% of unsatisfactory tests on milk from refrigerated farm tanks, but that only gross neglect seriously affected the count of fresh milk from refrigerated tanks.

Maxcy (1966) recognised that equipment could be a major contributor to the contamination of dairy products. The extent of the contamination varied considerably depending on the type and condition of the equipment and also the method of handling.

The common criteria for the evaluation of the cleanliness and the sterility of milking equipment, and thus the efficiency of the detergent and sterilant in conjunction with the cleaning system has been, firstly, physical cleanliness, assessed visually, and, secondly, the total number of either the residual viable organisms on the milk contacting surfaces, or else the bacterial content of the finished product. The assessment of cleaning efficiency by the examination of the finished product introduces other conflicting factors which may or may not be associated with the efficiency of cleaning. On the other hand, it would be argued that the presence of any residual bacterial flora which does not adversely affect the desired characteristics and quality of the finished product would be of academic interest, rather that of practical importance.

Quantitative bacterial flora of milk handling equipment.

Considerable work has been done on the quantitative aspect of the bacteriological population of washed and sterilised equipment, although the majority of the work has dealt with problems associated with the cleaning of bucket milking equipment and milking parlours, and more particularly with milking machine clusters. The latter are difficult to cleanse satisfactorily by virtue of the porous nature of the rubber liners and connections. Clegg (1957) has described these difficulties, and pointed out that these porous surfaces cannot be expected to be sterilised in depth where the infection rests in the short contact time usually permitted for chemical sterilisation. Major (1962) also showed the importance of milking machine rubberware as a source of bacterial contamination.

Cousins (1957), (1961) determined the applicability of a bactericidal rubber for use in the manufacture of milking machine inflations, and concluded that the use of rubber containing a powerful bacterial inhibitor was of doubtful value in reducing the bacterial counts of milking machine clusters. The use of synthetic (nitrile) rubber for milking machine rubber components, whilst resulting in lower bacteriological rinses than in an installation using components of natural rubber, was not effective in maintaining contamination below an acceptable level.

Thomas, Griffiths and Foulkes (1963) listed the majority of the reports published during the previous ten years dealing with the circulation cleaning of pipeline milking installations.

Other work published in the United Kingdom includes that of Baines (1962); Bird (1956); Carriere *et al.* (1955); Edgell and Widdas (1962);(1964); McCulloch (1963); Murray, Downey and Foote (1962); Murray and Foote (1963); Nokes and Tredennick (1965); Swift, Alexander and Scarlett (1963); Thiel (1959); Thomas, Jones-Evans, Jones and Thomas (1946); Thomas and Jones-Evans (1947); Thomas, Hobson and Elson (1958); Thomas, Jones, Hobson, Williams and Druce (1963); Thomas (1964); Thornborrow (1960) and Widdas (1961). Reports from other countries include those of Alexander, Nelson and Ormiston (1953); Calbert (1953), (1958); Dedek (1959); Downing (1953); Fleischman White and Holland (1950), (1953); Fortney, Baker and Bird (1955); Sheuring and Folds (1953); Hunter, Marth and Frazier (1954); Lindamood, Finnegan and Graf (1955) and Phillips (1962).

The officially recommended standard for satisfactorily cleansed equipment is less than 50,000/ft^2 (Ministry of Agriculture, Fisheries and Food, 1966b) whilst in North

America the standard is 3,000 colonies/ft^2 (Baines, 1962), but Thomas, Druce, Hobson and Williams (1963) suggested a satisfactory standard of not more than 10,000 colonies/ft^2 which could be easily maintained where sterilisation was carried out satisfactorily. They pointed out that 5,000 colonies/ft^2 for creamery plant is considered poor and that a good system of cleaning should give a count of not more than 1,000 colonies/ft^2 (Society of Dairy Technology, 1959).

Work published in the United Kingdom has indicated that the use of chemical sterilants alone is not sufficient to maintain a satisfactory hygienic condition without the application of heat. Cuthbert (1960) concluded that weigh jars and liner assemblies present cleansing problems which, it seems, can only be overcome by the use of heat for sterilising.

Widdas (1961) reported on an investigation carried out on 22 farms in England and Wales. The recommended treatment for cleaning was the circulation of a chlorinated alkaline detergent, and a chlorinated rinse to be drawn through the plant before each milking. The sterilising rinse was not generally practised since it would have delayed the beginning of the milking. Of the results, 57% had a count of more than 50,000 colonies/ft^2 and 30% of the counts exceeded 250,000 colonies/ft^2. This worker concluded that the recommended method of chemical sterilisation alone was not sufficiently effective and additional heat treatment would probably be required.

Middleton, Panes, Widdas and Williams (1965) showed that the introduction of a pre-chlorinated rinse resulted in an immediate improvement which was shown by the colony count of the rinses of the pipeline. This effect was not, however, reflected in the bacteriological quality of the milk. It was suggested that this could be due to the limited number of samples of milk examined. This result is more probably due to the dilution effect of the milk. It is pointed out by Baines (1962) and Cousins (1967) that a grossly contaminated line adds a disproportionately few bacteria to milk passing through the line. This is because rinse counts are measured in colonies/ft^2 whilst milk counts are recorded in colonies/ml. For this reason, low count milks can be obtained from a heavily contaminated line. Whilst this is an apparent contradiction to what has already been stated concerning the constribution that equipment has in the contamination of milk, equipment is the major source of contamination of the milk. The numbers of bacteria gaining access to the milk from equipment is more important, in types as well as numbers, than from the other two sources previously given.

Thomas, Druce, Hobson, and Williams (1963) examined the bacterial content of equipment sterilised by steam, boiling water, chemical immersion using caustic soda, chlorine and quaternary ammonium compounds, the sterilising effect of the last two being supplemented by periodic heat treatment and defatting of rubber fittings. It was found that a high percentage of satisfactory rinses was obtained on all farms using steam of scalding water, but only on some using immersion cleaning, chlorine or quaternary ammonium compounds. These results indicated the necessity of additional heat treatment when chemical sterilisation was being practiced. This is indeed recommended (Ministry of Agriculture, Fisheries and Food 1959) but a survey by Cuthbert, (1961) showed that of nearly one thousand producers using chemical sterilisation, only 24% applied weekly heat treatment and 9% subjected the equipment to occasional heat treatment.

Thornborrow (1960) reported the bacteriological results of a survey on circulation cleaning on 26 farms. The results indicated the value of heat, irrespective of whether it was used for the circulation of the detergent or for the final rinse. From the results obtained by rinsing clusters cleansed by cold circulating detergent solutions, 26% gave colony counts of over one million per square foot. When the detergent was circulated warm - up to 130°F - only 10% were unsatisfactory, with 0% when the detergent was over 180°F. Similar results were shown by Cuthbert (1960).

Thomas, Hobson and Elson (1964) found that sterilisation using sodium hypochlorite or detergent/sterilisers resulted in a high proportion of satisfactory counts when the sterilisation was supplemented by heat treatment. Generally, however, high rinse counts of more than 250,000/ ft^2 were more frequent with chemical sterilisation than where steam was used. The comparable figures given were 4% for steam sterilised equipment, 9% for chlorine, 15% for quaternary ammonium compounds, and 22% for immersion cleaning. Murray and Downey (1962) obtained similar results in Northern Ireland - 2% for steam sterilised equipment, 12% for chlorine and 14% where quaternary ammonium compounds were used.

Cuthbert (1961) has confirmed the necessity for periodic heat treatment to supplement chemical sterilisation in order to maintain a satisfactory hygienic standard. Clough and Thiel (1961) describing a system of cleaning and sterilisation of a modified parlour installation, used heat in addition to circulation cleaning techniques with a solution containing detergent and sodium hypochlorite with an initial temperature of 145°F. When sterilisation was effected only by the sodium hypochlorite there was an improvement in the rinse counts but they were again high by the time that the next heat treatment was due. With twice daily heat treatment the rinse counts were always satisfactory.

Edgell and Widdas (1962) noted that more than 50% of the colony counts of rinses of pipeline plants and recorder plants exceeded 50,000/ft^2, and as there was a high incidence of coli aerogenes organisms it was concluded that the cleansing routines being practiced were unsatisfactory. Thomas (1964) suggested that the absence of coli aerogenes organisms in 1 ml amounts of rinses could be used as an index of satisfactory cleaning and sterilisation. Their presence indicates that other types of heat-labile or thermoduric milk spoilage bacteria are likely to have survived the cleaning process. It has been found by the author that in one of eight installations examined, all presumptive coliform tests were invariably negative, although the total colony counts of rinses were not at a satisfactory level. No explanation is offered for this apparent anomaly, but it would appear that whilst the presence of coliform organisms is indicative of faulty cleansing techniques, the absence of this group of bacteria cannot be safely assumed to indicate the contrary.

Qualitative aspects of bacterial flora

Most of the studies mentioned above were directed towards the quantitative aspect of the bacterial population of the farm equipment and any findings as to the composition of the flora, where reported, were incidental to the main investigation. The qualitative aspect both in milk and in rinses has been comparatively neglected until quite recently. Even then, the majority of published work has been concerned with equipment or with milking parlour pipeline systems. Whilst these results may be applicable they are not necessarily directly related to thosefrom extended milk pipelines of considerable length, such as are used in 'round-the-shed' installations.

More than 35 years ago it was pointed out by Mattick (1930) that the keeping quality of milk depended not only on the number, but also on the type, of the bacteria present. More recently, Thomas, Druce and King (1966) observed that greater attention should be paid to the composition of the bacterial flora. It was noted by them that the keeping quality of milk from some farms where the pipeline rinse had high counts after circulation cleaning, was satisfactory and this directed attention towards the composition and milk spoilage activities of the microflora of different types of farm dairy equipment.

Milk spoilage activity

The occurrence of actively proliferating milk spoilage bacteria in the microflora of unsatisfactorily cleansed milking equipment has a more important effect on the keeping quality of raw milk in contact with such imperfectly cleansed surfaces than the purely quantitative aspect presented by total colony counts.

That not only do the types of organisms vary with the efficiency and method of cleaning, but also their relative activity has been shown by several workers, Thomas, Hobson, Elson (1964) found that there was a distinct change in the activity of organisms isolated from rinses, the variation differing with the system and efficiency of cleaning. Bacteria found on equipment which had been efficiently cleansed by the circulation of a detergent with added sodium hypochlorite were much less active in producing milk spoilage than those from poorly cleansed equipment.

A similar result had been found by Thomas, Druce, Hobson and Williams (1963) who reported that milk souring organisms producing rancid acid or proteolytic reactions were rarely found on equipment which had been sterilised by steam or scalding water. Where chemical sterilisation was practised there was a higher incidence of these milk souring types, particularly where such treatment was not supplemented by periodic heat treatment. The workers were carrying out an investigation on the effect of different sterilising methods - steam, boiling water, caustic soda, sodium hypochlorite or quaternary ammonium compounds - on the bacterial content of farm dairy equipment. Where equipment had been sterilised by steam, milk spoilage organisms were rarely found. This group of organisms however, was found to be much more frequent on milking machine clusters cleaned by immersion cleaning in caustic soda. There was a much higher incidence in rinses of equipment disinfected by sodium hypochlorite and actively proteolytic or acid producing organisms dominated the flora by quaternary ammonium compounds even when the rinse counts were low.

Griffiths and Thomas (1959) discussed the relationship of the colony count on Yeastrel milk agar for 72 h at 30°C, the coli-aerogenes test at 30°C and milk spoilage organisms at 22°C. A greater number of rinses of an unsatisfactory standard were found to be from rubber liners, whereas they were relatively infrequent with metal equipment. It was suggested that the test for milk souring organisms could be a useful index of unsatisfactory cleansing techniques to supplement the total colony count.

Thomas, Jones, Hobson, Williams and Druce (1963) examined the bacterial flora of farm dairy equipment and studied the activity of different cultures by noting the reactions in litmus milk after 72 h at 22°C. They found that the results could be broadly classified into four groups. The first group consisted of active milk souring types such as the streptococci and the coli-aerogenes organisms of which 88% and 81% respectively developed acid reactions. The second group were types in which a high proportion developed proteolytic reactions which included Gram-negative rods and aerobic sporeformers. The third group included those which were mainly inactive in milk - micrococci, corynebacteria, arthrobacteria and asporogenous Gram-positive rods. The fourth group comprised those types in which only a small proportion of the strains developed acid or proteolytic changes. It was pointed out that some types of bacteria appeared to be influenced by their source and environment. Of the Gram-negative rods isolated from steam sterilised equipment, 70% were inactive in milk, showing no change in 72 h at 22°C whereas 62% of those isolated from equipment sterilised by quaternary ammonium compounds developed proteolytic reactions and only 26% were inactive. The authors pointed out that the milk spoilage activity of the microflora of dairy equipment is influenced by the efficiency of sterilisation. Cultures isolated from efficiently sterilised or disinfected equipment were mainly inactive in litmus milk, whereas a much higher proportion of cultures isolated from high count rinses formed acid or proteolytic reactions.

It was also reported (Thomas, 1964) that 75% of the rinses from farms where the initial circulating temperature was 160°F or more had a keeping quality of 45 hours or more, determined by the clot on boiling test at 22°C. Only 50% of the rinses from farms using lower temperatures (135-140°F) attained this standard.

Petto (1962) points out that the value of the methods used for the determination of bacteriological quality of milk is now of questionable value and would appear to merit investigation and modification. Johns (1960) observed that dye reduction tests are becoming less and less reliable for the assessment of milk quality. These shortcomings become even more important with the efficient and rapid cooling of the milk, accompanied by longer holding times at low temperatures. Petto (1963) also posed the question whether the total number of bacteria present is of importance, or whether the type of organisms even if present in only small numbers, is of more importance in view of the different methods of utilisation of milk.

The proliferation of bacteria on cleansed equipment

The total number of bacteria present in milk depends not only on the degree of infection to which the milk has been exposed, but also on their growth between its production and subsequent processing. Such growth is affected, in turn, by the original composition of the bacterial flora, the type of organisms, the length of time that the milk is in transit, the temperature of the milk during this period and the ambient temperature.

The proliferation of bacteria is also dependent on factors enumerated above. Whilst it must be accepted that equipment is the major factor in the final contamination it has been pointed out by Maxcy (1964) that the extent of any contamination varies greatly depending on the type of equipment and the method of handling would provide a new environment for contamination and this could ultimately lead to a different flora of the contaminating bacteria. Thomas (1964) noted that the residual microflora varied quantitatively as well as qualitatively depending, amongst other factors, on the efficiency of the cleaning operation. Recent developments in milking equipment and methods, techniques in cleansing, milk collection and processing have indicated the necessity for more information on the bacterial flora in relation to survival and multiplication rates and the milk spoilage activities of the bacteria in raw and processed milks. Of the numerous different aspects involved in the composition of the bacterial flora and the importance of different groups of micro-organisms on the final utilisation of the milk, it must not be overlooked that the original flora of the cleansed pipeline is not necessarily reflected in that of the milk. Maxcy (1964) noted the diversity of the contamination in equipment cleansed in place and observed that there was neither a single source of contamination nor was the problem a single entity. But it was found that whilst contamination with a few predominating bacteria was apparent, the residual bacteria appeared as those which were more capable of surviving an unfavourable environment. This is in direct contradiction to that type of contamination which would appear as a result of residual milk residues undergoing fermentation and where a large proportion of lactic streptococci and coliform organisms would be anticipated.

Gibson and Abd el Malek (1957) discussed the development of bacterial population in milk and noted that of the range of types of organisms which are introduced, a large proportion find milk to be a relatively infavourable environment. Milk appears to have pronounced selective properties. The mechanism of this selection was difficult to specify. The growth rates of organisms differ; milk exhibits inhibitory effects on certain bacteria and some organisms that multiply in it have been shown to produce certain inhibitory substances. Cuthbert, Edgell and Thomas (1953) reviewing recent work on thermoduric bacteria in milk, showed that these organisms do not readily multiply in raw milk. On the other hand, Thomas (1964) stated that it is believed that many types of bacteria multiply more readily in milky residues or dairy equipment than in milk, due to the dilution of the natural bactericidal substances present in milk. Thomas, Jones, Hobson, Williams and Druce (1963)indicated the significance of the qualitative aspect of contamination and the sensitivity of the microflora to alterations in equipment and methods. This was also confirmed by other workers - Maxcy (1963) and Jackson and Clegg (1964). The nature of the microflora and the extent of growth is dependent on such factors as the thoroughness of cleaning which affects the extent of soil remaining for nutrients. Maxcy (1966) was of the opinion that the concentration of the soil in relation to the location of the contaminating organisms is of importance. With improved cleaning techniques both the concentration of the soil and the number of viable organisms would be reduced. For this reason those types of organisms capable of surviving with the lowest concentration of soil should therefore be the predominating organism in the bacterial population. It was shown by Maxcy that the residual soil is not distributed evenly throughout the pipeline system, but that the areas of maximum deposition included the pipeline joints and the pump.

Whilst smooth surfaces would appear to facilitate cleaning, Kaufmann, Hedrick, Pflug, Phiel and Keppeler (1960) have shown that there is not a direct relationship between surface and cleanability. Any residual microflora is therefore dependent on the relative availability of the nutrients from any residual soil. The moisture necessary for growth would be available since any installation cleaned by circulation methods invariably remains wet after cleaning. Growth would, however, be expected to be affected by the soil dilution. Maxcy and Shahani (1961) have shown that whilst organic residual soil was insufficient to interfere with chlorine sterilisation, there was still adequate residues to permit bacterial proliferation. Such residues were found to be incapable of measurement by radioactive techniques but were demonstrated by flooding the cleaned pipeline with a solution containing 2 p.p.m. (w/v) of available chlorine for approximately sixteen hours and measuring the dissipation of chlorine. The rate of dissipation was shown to be dependent on the quantity of the soil and the time of exposure. The use of swabs demonstrated that the soil was not uniformly distributed but concentrated at imperfections, such as joints, in the system, and this emphasises the importance of correct design of equipment, fittings and components. Any method of sterilisation which is not carried out efficiently must result in a form of selective bactericidal action which would permit the proliferation of certain types, whilst inhibiting or destroying others.

Thomas, Griffiths, Davies, Hobbington (1952), discussing the proliferation of heat resistant bacteria on dairy equipment, found that the conditions which result in a build up of a flora which was essentially thermoduric could be brought about by a continuous washing in hot water or detergents resulting in a partial selective sterilisation, the heat labile organisms being mainly destroyed, leaving a greater proportion of thermoduric organisms. Where equipment is only intermittently sterilised, being regularly washed in cold or warm water, the heat labile contamination builds up much more quickly than that of the thermoduric organisms. Gibson (1943) has stated that the organisms of the Bacillus cereus type become more numerous where the sterilising process, which is only capable of destroying organisms which do not sporulate, effect a selective bactericidal action and the number of sporeformers increase.

Thomas, Jones, Hobson, Williams and Druce (1963) found that even where satisfactory results were obtained using quaternary ammonium compounds, the residual bacteria were mainly active milk spoilage types and were dominated by Gram-negative rods.

Gibson (1943) explained that the comparatively high incidence of thermoduric organisms in glass releaser jars was due to the destruction of heat labile organisms whilst the treatment was insufficient to destroy the thermoduric organisms.

A similar effect would be the result of inefficient cleaning where the bactericidal effect of any detergent, however slight, would contribute to the composition of the bacterial flora Hedland (1957) pointed out that different cleaning methods for milking machines may favour specific micro-organisms, thus making the method selective. The residues which inefficient cleaning leave also offer protection for residual bacteria and milk residues would provide a source of food. Hammer and Babel (1957) stated that the presence of milk solids on inefficiently cleaned equipment provided conditions similar to those afforded by milk.

Lindamood, Finnegan and Graf (1955) showed that the effect of detergent compositon was of more importance than the temperature of the circulating detergent. It follows, therefore, that since this factor affects the total number of bacteria it would also affect the composition of residual bacterial flora. Any partial destruction of bacteria would therefore effect a form of selective sterilisation and hence groups which were resistant would therefore be present in the residual flora in greater numbers. In addition, should conditions encourage proliferation, such organisms would be present as the dominant group in the bacterial flora.

Carriere et al. (1955) investigating the effect of different sterilants on milking equipment found that the bacterial flora was affected by the installation as well as the method of sterilisation. Whereas micrococci predominated on equipment sterilised either by sodium hypochlorite or caustic treatment at one farm, another farm using caustic soda immersion exhibited a similar pattern but not with steam sterilisation. No explanation was offered for this phenomenon but it was believed that a change in the system of cleaning had resulted in a change in the composition of the bacterial flora.

Maxcy (1966) points out the influence of the relative availability of nutrients from the residual soil. Organisms capable of surviving on the lowest concentration of soil would predominate in any residual flora. Maxcy showed that with mixed raw milk, dilutions in the range of 10^{-3} to 10^{-4} were critical minimal levels to support growth. Maxcy and Shahani (1961) had already shown that equipment cleaned by circulation cleaning had less than 1 g of milk solids/ml of volume of equipment examined.

Maxcy (1966) showed that this soil was not evenly dispersed throughout the system. In the particular installation which he examined it was found in the gaskets of the joints of the pipeline cleaned _in situ_.

In addition to these factors, the growth rates of different groups of organisms vary and, whilst milk has been shown to exhibit inhibitory effects on certain bacteria (Abd el Malek and Gibson, 1952), it is conceivable that milk residues would also exhibit this inhibitory effect, whilst at the same time providing nutrients for other types of bacteria.

These are not the only factors which control the composition of the residual bacterial flora. The specific installation can also present an environment which may contribute to the predominant flora. Thomas, Druce and King (1966) have shown that characteristic types of microflora were frequently associated with certain environments or sources when such equipment was not cleansed satisfactorily.

Composition of bacterial flora on farm dairy equipment

Composition of bacterial flora on farm dairy equipment

Thomas, Druce and King (1964) have listed some of the authors of work who have indicated the predominant types of bacteria found on cleansed dairy equipment. Some of the reports quoted were not investigating the flora of farm dairy equipment, but the results are valuable in indicating the methods of differentiation and identification used and also the groups of organisms observed.

Thomas, Druce, Hobson and Williams (1963) carried out a comprehensive investigation dealing with the effect of different methods of sterilisation on the bacterial content of farm dairy equipment. The information was obtained from rinses taken on 35 farms over a period of seven years. Where the sterilisation had been effected by steam, it was found that the bacterial flora was dominated by micrococci, with corynebacteria and aerobic sporeforming rods frequent. Milking machine clusters efficiently cleansed by immersion in caustic soda were also shown to have a bacterial flora of similar composition as were bucket plants efficiently cleansed by detergent sterilisers containing sodium hypochlorite.

These results broadly agree with those obtained by other workers investigating different dairy equipment - Crossley (1944), creamery plant; Hoy and Rowlands (1948), milking machine clusters; Hughes and Ellison (1948), satisfactorily washed milk cans; Edgell and Widdas (1962), farm pipelines cleaned by circulation methods; Maxcy (1964), creamery pipelines; Jackson and Clegg (1964), farm pipelines cleaned by circulation.

Other work by Thomas and his co-workers has also confirmed that the composition of bacterial flora of equipment which had been satisfactory cleansed were similar in different investigations. (Thomas, Druce and King, 1964; Thomas, Hobson and Elson, 1964; Thomas, Jones, Hobson, Williams and Druce, 1963).

There is, however, not the same agreement between different workers on the composition of bacterial flora of equipment which was unsatisfactorily cleansed having either medium or high rinse counts.

Thomas, Druce and King (1963) found that where milking machine clusters were inefficiently cleaned by immersion cleaning in caustic soda, resulting in colony counts greater than 60,000/ft^2, active milk souring organisms, streptococci and Gram-negative rods, constituted approximately 70% of the flora. Similar results were also obtained from bucket plants sterilised by sodium hypochlorite. In a later investigation Thomas, Hobson, and Elson (1964) found that equipment cleansed with a detergent/sodium hypochlorite or organic chlorine compounds, had a flora in which Gram-negative rods constituted 32% whilst micrococci and streptococci together constituted approximately 35%. A survey of the microflora of poorly cleansed farm dairy equipment made by Thomas, Druce and King (1966) indicated that characteristic kinds of microflora were more frequently associated with certain sources. Micrococci and corynebacteria dominated flora were most frequent on rubber components but coli-aerogenes organisms were also frequently found on milking machine clusters. More active milk spoilage types of Gram-negative rods predominated in flora from pails and cooling units. More of the pipeline milk plant rinses had a flora dominated by streptococci than other types of equipment but it was pointed out that this may have been influenced by differences in cleaning operations at the farm.

Thomas *et al.* (1963) reported that the bacterial flora obtained from pipeline milking plants varied with the system and efficiency of cleaning. Where the detergent steriliser containing sodium hypochlorite was circulated at a temperature of 180-190°F the rinse count rarely exceeded 50,000 colonies/ft^2, and was dominated by micrococci (80%) with corynebacteria and aerobic sporeformers together constituting a mere 15% of the total flora.

At another pipeline installation, where the detergent/sodium hypochlorite was circulated at an initial temperature of less then 150°F, unsatisfactory colony counts of over 100,000/ft^2 were often observed and the bacterial flora was dominated (70%) by an organism identified as *Streptococcus faecalis* var. *liquifaciens* which could only be eradicated by the replacement of all rubber fittings and the circulation of the detergent at 180°F.

The third pipeline had a variable cleaning treatment the detergent/sodium hypochlorite being circulated sometimes at 120°F and sometimes at 130°F. The rinses were unsatisfactory giving colony counts often exceeding $10^6/ft^2$ and the bacterial flora was mixed, 45% being heat labile organisms including 29% of coli-aerogenes. It was pointed out that these results agree with those of Edgell and Widdas (1962) who investigated the different makes of machine designed for in place cleaning using the manufacturer's cleaning routine with alkaline detergents and approved sodium hypochlorite solutions.

Thomas (1964) reported that unsatisfactorily cleansed equipment which gave rinse counts much greater than $250,000/ft^2$ was characterised by a flora dominated by streptococci and Gram-negative rods whilst micrococci and corynebacteria were relatively uncommon. Where such equipment which had been washed by hand, was sterilised by chlorine, the dominant organisms were streptococci (24.8%) with micrococci common (19.7%) and streptococci and non-pigmented Gram-negative rods frequent (15.5% each). With pipelines cleansed by circulation methods, the dominant organism was again streptococci (57.8%) with micrococci frequent (14.9%). The predominance of streptococci in cleansed pipelines agrees with other work with which Thomas was associated (Thomas, Druce and King, 1966).

Jackson and Clegg (1964) found that on inefficiently cleansed pipeline milking plant, particularly where the temperature of the circulating detergent/steriliser was less than 140°F, the flora was dominated by Gram-negative rods, including coliforms and streptococci.

Abd el Malek and Gibson (1952) found that the flora of inefficiently cleansed dairy equipment was dominated by Gram-negative rods with micrococci and aerobic sporeformers frequent.

From this study of the work which has been reported it seems that the composition of the bacterial flora of efficiently cleansed dairy equipment is the same irrespective of the method of sterilisation or the type of equipment. There appears, however, to be less agreement in the composition of bacterial flora of equipment where the cleansing has been carried out either inefficiently or indifferently. Whilst some groups of organisms occur more frequently in the bacterial flora, the variety of organisms is more complex. It is pointed out that the method and effectiveness of the cleansing are but two factors which contribute to the number and type of bacteria found in the residual flora of equipment.

Not only are the numbers of bacteria in the residual flora important but also the type of organisms as well as their milk souring activity. Any critical evaluation of the efficiency of cleansing of dairy equipment should incorporate a value for all three of these factors.

THE RELATIONSHIP BETWEEN THE TEMPERATURE OF DETERGENT CIRCULATION AND THE BACTERIAL FLORA OF PIPELINES WASHED BY CIRCULATION METHODS

The satisfactory production of milk of good keeping quality is dependent on the standard of cleaning of the equipment. Where the cleaning is effected by circulation methods the efficiency of cleaning is reflected in the number and types of any residual bacterial population in the milk pipelines. There are many reports dealing with the bacteriological aspects of circulation cleaning in milking parlour systems but comparatively little attention has so far been paid to the bacterial flora in pipelines of 'round-the-shed' milking installations. Most of the available literature dealing with this aspect has been summarised by Thomas (1963).

An investigation was made to determine whether the findings of other workers, working with parlour installations, agreed with similar work carried out on 'round-the-shed' installations in the South West of Scotland.

PART I RELATIONSHIP BETWEEN TEMPERATURE OF CIRCULATING DETERGENT AND THE TOTAL COLONY COUNT OF PIPELINE RINSES

Installations. An investigation was carried out to determine the bacterial flora of washed pipelines at eight commercial farms over a period of time. The milking equipment at one farm was examined at variable periods over four years, with rinses taken fortnightly. The remaining farms were sampled at the same interval, over different periods of time, ranging from six months to three years.

Farm A. had a double sided milking byre with a stainless steel pipeline, joined at the distant end by a galvanised cross pipe. The length of the pipeline was approximately 60 feet, and the installation used Gasgoigne fittings. The hot water was supplied by one 50 gallon electric water heater.

It was found that seven of the installations used one of two proprietary alkaline circulating detergents. Their approximate composition, with that used by the eighth installation, is given below. Farm A used detergent A with added sodium hypochlorite.

Farm B. was a large double byre with a new Fullwood installation which included a Fullwood automatic control system for cleaning. There were 135 feet of glass pipeline and the water was supplied by one 50 gallon hot water storage heater. The detergent used was B and to this was added sodium hypochlorite.

Farm C was another Gascoigne 'round-the-shed' installation with a double T-shaped byre, although all the standings were not used for milking cows. The pipeline was of glass and was 170 feet in length. The hot water was supplied by a steam boiler which burned wood. The detergent used was detergent B and to this the sodium hypochlorite was added.

Farm D was a Gascoigne 'round-the-shed' installation with the double byre. The pipeline, which was 78 feet in length, was of stainless steel. Hot water was supplied by one 50 gallon electric water heater and the full washing treatment was carried out after each milking. The detergent which was used was detergent A to which was added sodium hypochlorite.

Farm E was a new installation with a large double byre. The installation was by Alfa Laval and there were 250 feet of stainless steel pipeline. Hot water was supplied by one 75 gallon water heater and the detergent used was detergent A, with the addition of sodium hypochlorite.

Farm F was an Alfa Laval 'round-the-shed' installation with 150 feet of stainless steel pipeline. The detergent which was used was not one designed for circulation cleaning, and was sold for general purpose cleaning. This was circulated with the correct amount of sodium hypochlorite. Hot water was supplied by one 50 gallon electric water heater

Farm G was an Alfa Laval 'round-the-shed' installation which was an older installation and which included a separate return line. The length of the stainless steel milk line was 80 feet, and the cleaning was done by detergent B with the addition of sodium hypochlorite.

Farm H was an extended milk lift with only one pick-up point The pipeline was only 30 feet in length and the installation was by Alfa Laval. The detergent which was used was detergent A with the correct amount of sodium hypochlorite. The hot water was supplied by a steam boiler which burned coal.

Composition of detergent used for cleaning. Seven of the installations used one of two proprietary circulation alkaline detergents. In the eighth installation the circulation was carried out with a detergent which had been formulated for general purpose cleaning. In all cases, except one, the detergent was circulated with added sodium hypochlorite to give a concentration of 250-300 p.p.m. available chlorine. The exception was with installation 8 where the cleaning was controlled by an automatic device where the detergent circulation was followed by a rinse and a final sterilising rinse containing approximately 50 p.p.m. available chlorine.

The approximate compositions of the three detergents are as follows:-

Detergent A		Detergent B	
sodium metasilicate	35%	sodium metasilicate	40%
tri-sodium ortho-phosphate	55%	sodium carbonate (anhydrous)	40%
sodium tripolyphosphate	9%	sodium hexameta-phosphate	20%
non-ionic detergent	1%		

Detergent C	
sodium carbonate (anhydrous)	65%
sodium metasilicate	25%
sodium polyphosphate	10%

Preliminary treatment of milking installations. There was no preliminary treatment of the milking equipment, such as the descaling of the pipelines or the renewal of any rubber fittings, nor was any alteration made in the method of cleaning or the detergent used. It was considered that any alteration in the system of cleaning would give an incorrect picture of the bacteriological standards which were being maintained by the producer. During the investigation it became obvious that the results obtained on several of the farms in the investigation could not be considered as satisfactory when judged by standards which are generally accepted as being satisfactory (Ministry of Agriculture, Fisheries and Food, 1955a,b) when the total count of rinses should not exceed 50,000 colonies/ft^2, but no effort was made to correct any obvious faults in the cleaning system during the course of the investigation.

Measurement of circulating temperatures. The maximum temperature of the circulating solutions were determined by attaching a series of paper thermometers to the solution inlet and outlet (Wenz et Cie., London). These paper thermometers are strips of sensitised paper which turn black when the temperature attains a certain predetermined figure. By this means it was possible to obtain a permanent record of the maximum temperatures attained during the circulation. These strips were attached to the exterior of stainless steel parts of the equipment since the external surface of glass equipment would give a lower reading of the circulation temperature due to the poorer conducting characteristics of the glass. (Plates 6 & 7).

Method of sampling. Rinses were taken of the cleansed pipeline by drawing from the most distant stallcock a measured volume of ¼ strength Ringer solution containing 0.5% (w/v) sodium thiosulphate to neutralise any residual chlorine picked up by the rinse in the pipeline. The volume of the rinses depended upon the length of the pipeline. Sufficient was used to permit approximately 500-600 ml to collect in the receiver jars. In the majority of the installations in the investigation this necessitated an initial volume of 4 litres.

In some of the installations the pipeline was U-shaped rather than a complete circuit, and the two arms were only connected during the washing operation. With such installations, half the sterile rinse was drawn through the most distant stallcock of each arm, with the cross pipe either disconnected or isolated by means of a butterfly valve.

With the vacuum pump operating, a sterile long milk tube was inserted in the flask containing the rinse, which was drawn up through the stallcock, into the pipelines and to the receiver jars. From this point the rinse was delivered by the operation of the milk pump through the milk delivery pipe and collected in a sterile flask.

The rinses were tested within five hours of sampling.

Media. It was intended to determine the proportions of different groups of bacteria using different selective media. It was felt that were such determination made using colonies selected from those cultivated on Yeastrel milk agar, any results would not necessarily be a true indication of the actual flora of the pipeline. Any method of bacterial cultivation, whatever the medium, even milk, could be selective in encouraging the growth of some types of organisms and inhibiting others. This was noted by Carriera et al. (1955) who, in examining the effect of different methods of sterilisation of equipment on the bacterial flora of the milk, found that the bacteriological results did not agree with the determination of the flora by the identification of the isolates. The coli-aerogenes results, using MacConkey's broth gave values which were twice those obtained from the total count. It was pointed out that the method of the determination of fractions of the flora by plating can be most misleading.

Thomas, Druce, Hobson and Williams (1963) noted that the method used in numerous investigations provided information only of the incidence of the predominant types of bacteria capable of producing colonies of Yeastrel milk agar in 72 h at 30°C. It was also pointed out that types of organisms occurring in relatively small numbers could be missed during the selection of the colonies to be identified. It was suggested that selective media be used for the detection of specific types of organisms. Carriere et al. (1955) had also concluded that it would be necessary to use selective media for all the different fractions which it was desired to study.

The following bacteriological methods and media were used:-

Colony count. The total count was determined using Yeastrel milk agar and incubating dilutions of 10^{-2} and

10^{-3} of the rinse at 30°C for 72 h. Yeastrel milk agar, the official medium described by Ministry of Health Memo (1937) is used extensively for the determination of the colony count on milk and milk products as well as rinses and swabs of dairy equipment. 10 ml of the molten agar, cooled to approximately 45°C are added to the dilution in a sterile Petri dish. The agar and the dilution are thoroughly mixed and then set aside to solidify. The plates are allowed to stand on the bench for approximately an hour and are then transferred to the incubator where they are incubated for 72 hours at 30°C. (Davis, 1959).

Mannitol salt agar. The colony count was taken after incubation at 37°C for 36 h on mannitol salt agar, on undiluted rinse, and on 10^{-1} and 10^{-2} dilutions of the rinse. The mannitol salt agar was obtained from Oxoid Ltd , London, who recommended its use for the isolation of presumptive pathogenic staphylococci. Presumptive coagulase-positive staphylococci produce colonies with bright yellow zones whilst non-pathogenic staphylococci produce small colonies which are surrounded by purple zones. Further diagnostic tests were not regularly attempted, the count from this medium being used to provide a comparative figure of the total number of staphylococci which were highly salt tolerant and which may, or may not have been coagulase positive.

Rogosa agar. The colony count was made after 120 h with an incubation temperature of 30°C on Rogosa agar on undiluted rinse, and on 10^{-1} and 10^{-2} dilutions of the rinse. The Rogosa agar used was a modification of that described by Rogosa, Mitchell and Wiseman (1951) and was obtained from Oxoid Ltd., London. The method suggested by Sharpe (1960) was followed; the inoculated plate being overlaid with a second layer of Rogosa agar before being incubated.

Violet red bile agar. The number of colonies which developed on violet red bile agar after 24 h at 37°C from the undiluted rinse and also on dilutions of 10^{-1} and 10^{-2} of the rinse, were counted. The use of violet red bile agar has been suggested by Davis (1961) and also the American Public Health Association (1953) for the presumptive test for coliform organisms. Whilst this was also effected by MacConkey's Broth, the use of this medium permitting the enumeration of the organisms.

Count of Gram-negative organisms. The colony count of Gram-negative organisms at 72 h at 30^{0}C was made using Yeastrel milk agar to which was added 1% of a 0.05% (w/v) solution of crystal violet immediately before pouring. The count was made on undiluted rinse, and on the 10^{-1} and 10^{-2} dilutions of the rinse.

In an examination of the organisms present in the soil, Holding (1954) found that, out of several different media tested, nutrient agar containing 2 p.p.m. of crystal violet gave the highest count of Gram-negative bacteria. In a subsequent investigation, Holding (1960) used this medium to isolate and count Gram-negative bacteria in soil. In work related to the influence of the pseudomonads in the contamination and deterioration of market milk, Gyllenberg, Eklund, Antila and Vartiovaara (1960) suggested the use of ammonium lactate agar containing crystal violet in the proportion of 1:500,000 and they reported that Gibson, Stirling, Keddie and Rosenberger (1958) used a medium of a very similar composition for the enumeration of Gram-negative organisms from silage.

Count of thermoduric organisms. This was the count of organisms which survived laboratory pasteurization of the rinse for 30 min at 63^{0}C, determined by plating on Yeastrel milk agar and incubating for 72 h at 30°C. To 8 ml of sterile separated milk were added 2 ml of the rinse and the tube held at 63°C for 30 minutes when it was cooled and 10^{-1} and 10^{-2} dilutions plated.

Count of total spores. To 8 ml of sterile separated milk was added 2 ml of the rinse and held at 80°C for 10 minutes, cooled and 10^{-1} and 10^{-2} dilutions plated with Yeastrel milk agar and incubated at 30°C for 72 h.

Milk spoilage organisms. Into 10 ml of sterile litmus milk was inoculated 1 ml of the rinse and incubated at 22°C. Indications of bacterial growth were recorded after 24 hours and 48 hours.

Coli-aerogenes test. Into three tubes of MacConkey Broth were inoculated 1 and 2 ml of the rinse and the tubes incubated for 72 h at 30°C. The presence of acid and gas production in two of the three tubes was recorded as positive.

RESULTS

The total colony count of the rinses of the individual installations compared with the initial temperature of the circulating detergent in the trough, and also the maximum temperature achieved by the detergent recorded at the return pipe, are shown in Tables 6 and 7.

The relationship between different temperatures of the circulating detergent solution, or the total colony count of the rinses with different groups of bacteria for the eight installations examined are shown in Tables 8 and 9.

DISCUSSION

Relationship between total colony count and initial circulating temperature. There is a distinct inverse relationship between the increased temperature of the circulated detergent and the total colony count of the rinse. The only discrepancy in this observation is where there were a small number of rinses taken in one temperature range - e.g. Farm B where a circulation temperature of 140°F was used twice.

The increase in temperature is but one factor which may result in increased efficiency which is reflected in a reduction in the total colony count. Farms A, B and C did not attain a satisfactory bacteriological standard, as determined by the colony count, until the initial temperature of the circulating detergent reached 170°F. This temperature is difficult to attain by many farm installations and that it was found necessary in these three instances would indicate the poorer cleansing techniques being practised. This is particularly emphasised by the results obtained by other farms in the investigation where lower temperatures resulted in more satisfactory results. Whilst firm conclusions could not be made from the last three farms - F, G and H-which had a limited number of rinses, D and E had markedly better results - i.e. less than 50,000 colonies/ft^2 - with temperatures of 160°F and 140°F respectively. It would appear that management of those two farms was better with respect to the cleaning of the milking equipment, and this is reflected in a more satisfactory hygienic condition being obtained with lower temperatures and hence at lower cost.

<u>Relationship between the total colony count and maximum outlet temperature.</u> The effect of the outlet temperature and the total colony count of the rinses is shown in Table 7. With increasing temperature of the returning circulating solution the total count decreased. This temperature is influenced by the initial temperature of the detergent, whether the pipeline has been heated by an initial flushing of either hot water or detergent, and the length of the pipeline circuit.

It was noted that the maximum temperature attained during the circulation at the outlet exhibited a more direct relationship with total count than did the initial temperature of circulation. This was applicable for all the eight installations examined irrespective of the length of the pipeline or the initial temperature of the detergent.

Relationship between different temperatures of circulation and the occurrence of various groups of bacteria. The results which are given in Table 8 indicate that in the majority of the farms the proportion of the lactobacilli present in the rinse increased as the temperature of the circulation rose. This was clearly not so, however, with Farm A, where over a temperature range of $140^{0}F$ to $180^{0}F$, the count using Rogosa agar, did not follow this general pattern. In addition, the proportion of lactobacilli in the total bacterial flora was much lower than for any other of the other farms examined - approximately 23% whilst the others were in the range of 32% - 90%.

A higher proportion of the total count for Farms A and C developed on mannitol salt agar when compared with the other farms - 48% and 27% respectively whilst the others ranged from 3% to 10%. In Farm B this proportion was only 27% at the lower temperature of 140°F. The ratio of organisms developing on mannitol salt agar compared with the total number on all the selective media, remained constant, irrespective of temperature, with Farm A, but with Farm C there was a decrease in the ratio as the temperature rose from 120°F to 170°F from 33% to 21%. With the other farms, other than A, there was a decrease with increasing temperature. With A the proportion remained materially constant between 38% and 60% irrespective of temperature

The proportion of the colonies growing on violet red bile agar did not appear to follow any definite pattern, either as a result of different circulating temperature or between different installations. Violet red bile agar is a selective medium for the enumeration of coliform organisms. Farm A had very low counts, which was quite surprising in view of the unsatisfactory level of rinse counts on Yeastrel milk agar, and the poor standard of hygiene at the farm. The rinses had been taken over an extensive period of time of more than four years, although no rinses had been taken between April and September in any one year. Farm B had a high count after lower circulation temperatures, nearly 50% of the total count obtained on the different selective media being on violet red bile agar. This proportion was reduced at higher circulating temperatures, although it was still 18% when a circulating temperature of 170°F had been used. This last result, however, was for only one rinse.

Farm C had a count on violet red bile agar which varied but little with change in temperature, being 10% - 20% of the total count.

There did not appear to be any distinct relationship between the results obtained by the use of MacConkey Broth and those from the use of violet red bile agar. In some instances a count of 12% of the total count of organisms obtained on all the selective media corresponded to 100% positive results with MacConkey Broth. In other instances 46% of the total count was reflected in only 50% positives with the MacConkey Broth. It was found that these anomalies would not have been so great had additional differentiation been regularly carried out on the colonies which had developed on the violet red bile agar. In some cases such further differentiation was carried out and it was found that some colonies, which had appeared as small colonies on the plate, produced only an acid reaction when picked off and inoculated into MacConkey Broth. It would appear that these bacteria fermented lactose but were not coliforms, although they appeared to exhibit some tolerance for the sodium glycocholate in the agar.

It was most surprising to note the low count on violet red bile agar, coupled with the complete absence of positive presumptive coliform tests on all the 76 rinses made on the equipment at Farm A. At no time during the investigation was a positive coliform result recorded, irrespective of the temperature of the circulating detergent solution or the total colony count on Yeastrel milk agar.

The presumptive coliform test is still used as one of the statutory tests in Scotland for designated milks, Milk (Special Designation), (Scotland) Order, 1965. Its importance with regard to dairy farmers is emphasised by the details concerning the results of milk samples taken in Ayrshire during 1965/6.

	% samples passing statutory tests	% Failures			
		Total	high count and coliform	high count only	coliform only
1966	82.5	17.5	4.4	9.4	3.9
1965	81.2	18.8	1.6	1.0	16.2

(Ayrshire County Council, 1967)

The statutory regulations in operation in Scotland for tuberculin tested milk until the end of 1965 (Milk (Special Designations) (Scotland) Order, 1951) demanded a plate count of not more than 200,00 colonies/ml. This was changed from January 1st 1966 (Milk (Special Designations) (Scotland) Order, 1965) to a maximum permissible plate count of 50,000 colonies/ml for 'standard' milk, a new grade which superseded tuberculin tested raw milk. At the same time the standard for coliform organisms was changed from being absent in 1/100 ml to absent in 1/1000 ml. These changes in standards resulted in a greater proportion of the failures being the result of high total colony count.

The proportion of the Gram-negative organisms, determined by the use of Yeastrel milk agar with added crystal violet when compared with the total count on all selective media, showed no regular pattern.

Farm A had a low relative ratio of 2% - 7%, except for the 22 rinses taken when the circulating temperature was 160°F. In this case the level rose to 30%.

Other farms had a high, but fluctuating, proportion of organisms developing on this medium. Whilst Farms F, G and H had a low, or nil, count, Farm C had a value which remained approximately 15% - 20% of the total irrespective of the temperature.

Sporeforming organisms increased slightly as the temperature rose, but their occurrence remained materially constant in the temperatures found during the investigation. The variation for any particular installation, with the exception of Farm G, was less than between different installations The single exception is probably explained by the fact that the results represent only one rinse.

The count of the thermoduric organisms tended to rise with increasing temperature of the circulating detergent, but it was noted that the relative proportions of thermodurics varied considerably between installations irrespective of the temperature involved.

The occurrence of milk spoilage organisms was greater in pipelines cleaned by low temperature circulation, although some of the installations examined showed a high incidence of these groups even where the temperature was as high as 160°F - milk spoilage organisms were present in 60% of the rinses of Farm B at this temperature - whereas another installation, Farm F, even with a circulating temperature as low as 140°F showed that none were present.

The test for milk spoilage organisms (48 H at 22°C using litmus milk) does appear to be a satisfactory index of cleaning efficiency since an installation which showed a high total colony count, even with a circulation temperature of 150-160°F also showed a relatively high incidence of milk spoilage organisms. Conversely, where a satisfactory state of bacteriological hygiene is achieved with a lower circulation temperature, as with Farms F and H, the presence of milk spoilage organisms was not detected. This result was found by Griffiths and Thomas (1959) who, in the course of investigating the bacterial count of farm dairy equipment found that the milk spoilage organism test was much more sensitive than the coliform test. They found that the former test was rarely positive in rinses which gave counts within the level of 10^4/cluster, which was considered by them to be satisfactory.

PART II RELATIONSHIP BETWEEN TEMPERATURE OF CIRCULATING DETERGENT AND THE COMPOSITION OF THE BACTERIAL FLORA.

It has been observed by different workers (Mattick, 1939, Thomas, Druce and King, 1966, and Petts, 1963) that greater attention should be paid to the type, as well as to the numbers of bacteria present on the surface of milking equipment. In parallel with the investigation described above relating the total colony count with the temperature of the circulating detergent, studies were made to identify representative colonies from the plate on the primary rinse of the equipment and relate the bacterial flora with the total colony count and also the different temperatures of circulation.

The most comprehensive and recent investigations into the incidence of different types of organisms occurring in rinses of cleansed dairy equipment have been by Thomas and his co-workers who have determined the types and numbers of the bacterial flora under different conditions. (Thomas, 1963; Thomas, Druce, Hobson and Williams, 1963; Thomas, Griffiths and Foulkes, 1963; Thomas, Druce and King, 1964; and Thomas, Hobson and Elson, 1964).

METHODS

An investigation was made of the different types of organisms which developed colonies on Yeastrel milk agar from the primary rinse counts. From a plate containing less than 300 colonies obtained in the total colony count (72 h at 30°C) 24 colonies were picked off, using the random selection disc and method described by Harrison (1938). The method of preparation of the pure cultures followed that described by Thomas, Druce, Hobson and King (1963). The colonies were picked from the plate into Yeast dextrose Lemco broth and incubated at 30°C for 24-72 hours. The cultures were then purified by streaking on to poured Yeastrel milk agar plates and differential tests were then carried out on these pure cultures.

The organisms were stained by Gram's method and examined microscopically. The catalase test was carried out by pouring 1 ml of 10V hydrogen peroxide over the growth of a 24 hour agar slope culture, setting the tube in an inclined position. The evolution of gas bubbles indicated a positive result (Topley and Wilson, 1955).

From these two basic tests, the cultures were classified into the following groups: micrococci; Gram-positive rods; streptococci; staphylococci; and Gram-negative rods.

The Gram-positive rods were further sub-divided into corynebacteria, identified by the characteristics appearance under the microscope, and other Gram-positive rods.

The only additional classification was that of the Gram-negative rods. The cultures were inoculated into MacConkey Broth to differentiate coliform organisms, and also into litmus milk in order to determine whether the culture exhibited proteolytic activity. From these additional tests three additional groups were obtained. Gram-negative rods were sub-divided into Gram-negative rods, non-proteolytic; Gram-negative rods, non-proteolytic;

and coliforms.

Whilst further classification was attempted on different cultures in the course of the investigation, such as the isolation of sporeforming types or the determination of the coagulase reaction, these were not carried out on all the isolates obtained and any results are therefore not included.

Any isolates which did not fall into any of the categories listed above were described under 'miscellaneous'.

RESULTS

The results of the bacterial flora of rinses in relation to the total colony count are shown in Table 10. The bacterial flora of the rinses in relation to the temperature of the circulating detergent is shown in Table 11.

By comparing the proportion of the number of isolates to the total count of the primary rinse it can be seen that there was a pattern of their incidence in relation to the total colony count.

The numbers of micrococci decrease with increasing colony count, as does corynebacteria. Other Gram-positive rods do not show any great change but groups of micro-organisms which are indicative of unsatisfactory production methods and management, such as streptococci or coliforms increase with increasing colony count. These results agree with those obtained by other workers working with farm dairy equipment. (Thomas, Jones, Hobson, Williams and Druce, 1963; Thomas, Hobson and Elson, 1964).

When the results of isolates from individual installations are examined (Table 9) it can be seen that there are some quite distinct characteristics which are different from the general pattern.

The bacterial flora of pipelines at Farm A was predominatly micrococci, and, to a lesser extent, coryne-bacteria for the low count rinses. It was the same with medium and high count rinses although the proportion of both progressively decreased. The occurrence of proteolytic and non-proteolytic Gram-negative rods was lower than the average of all the farms in the investigation. Coliforms were infrequent, not only in low count rinses, but also in the high count rinses.

Farm B had a very high proportion of micrococci with a lower proportion of corynebacteria than the other instal-lations in the investigation. With high count rinse isolates there was a greater number of proteolytic Gram-negative rods. Similarly, the occurrence of coliforms was higher in high count rinses.

Farm C had a flora which was predominantly streptococci, staphylococci and Gram-positive rods for the low count rinses. High count rinses had a more complex flora with coliforms, proteolytic Gram-negative rods, staphylococci and streptococci. For approximately three months the cleaning at this farm was changed from the conventional alkaline detergent with added hypochlorite to the circulation of an iodophor which was circulated cold, and the foaming for which this type of compound has a marked propensity, was controlled by the addition of a proprietary anti-foaming compound, based on silicones. This method of cleaning, however, and the total colony counts obtained during this method often exceeded $10^6/ft^2$ (Table 10c(ii)). The bacterial flora of rinses of this equipment which had been washed in this manner and which had counts between 25000 and 1000000 colonies/ft^2 comprised mainly of streptococci, staphylococci and micrococci. With high rinse counts the microflora was complex, with high proportions of streptococci, staphylococci and with Gram-negative rods, both proteolytic and non-proteolygic and coliforms, common. There were no rinses taken which had a count less than 25000 colonies/ft^2.

In low count rinses, obtained at Farm D there was a predominance of micrococci and corynebacteria. There was, however, a higher proportion of Gram-positive rods than the average of all eight farms. The Gram-positive rods increased in proportion with increasing count. Coliforms were present in even low count rinses.

Low count rinses from Farm E were dominated by micrococci, but with increasing count the microflora became more complex, with coliforms being common. In high count rinses streptococci, micrococci, staphylococci and coliforms common.

The microflora on low count rinses for Farm F was dominated by micrococci, corynebacteria and non-proteolytic Gram-negative rods. Increasing count resulted in the development of a more complex flora, and high count rinses had a high proportion of staphylococci and Gram-negative rods. Coliforms were also present, although in smaller numbers.

Only low count rinses were found in the small number of rinses taken from Farms G and H - three and two respectively. Micrococci, corynebacteria and Gram-positive rods comprised the largest groups. The flora from Farm H had fewer types and only micrococci, Gram-positive rods and non-proteolytic Gram-negative rods were present in any numbers.

DISCUSSION

Relationship between the temperature of circulation and total colony count. Rinses were taken of the milk pipelines of eight farms which were all washed and sterilised by circulation cleaning. The total colony count of the rinses on Yeastrel milk agar after 72 h at 30°C were examined in relation to the maximum temperature recorded at the beginning of the circulation and also the highest temperature recorded at the solution outlet. In both cases it was found that the higher temperature corresponded to a lower colony count. The initial temperature necessary to give a count which was considered to be satisfactory - less than 50,000/ft^2 - varied considerably between different farms, and ranged from 130-160°F. There was a closer relationship between a satisfactory colony count and the solution outlet temperature, and it is suggested that temperatures of circulation should be taken at this point. Variations in the temperature necessary to ensure a satisfactory standard of hygiene given by other workers (Calbert (1958), 130°F: Cuthbert

(1960), 160°F: Fortney *et al.* (1955), 170°F and others) could be the result of either the temperature at the inlet or the outlet being reported.

From the results obtained on the eight farms examined, it would appear that, with one exception, a minimum outlet temperature of 140°F is necessary to give satisfactory results. The exception was one producer who had particular difficulty in attaining a satisfactory hygienic condition and the minimum outlet temperature necessary in this case was 150°F. An outlet temperature of 140°F would require, principally depending on the length of the pipeline, an initial circulation temperature of 140°F to 170°F. This agrees generally with the findings of Baines (1962).

Relationship between the temperature of circulation and groups of organisms cultivated on different selective media. By the use of different selective media, the approximate composition of the bacterial flora of cleansed pipelines was compared with the temperature of circulation. It was seen that there were variations from one farm of those installations studied to another depending on the temperature of circulation and the total colony count, although these factors are themselves inter-related. The majority of farms showed an increase in the lactobacilli content of the bacterial flora with increasing temperature.

Two farms had a high count of salt tolerant organisms presumably staphylococci when compared with the other farms in the investigation. Of these two farms, one showed a decrease in count of this group of bacteria with an increase in temperature whilst the other showed no alteration with temperature.

There did not appear to be any direct relationship between the count on violet red bile agar, the result of the presumptive coliform test and temperature of circulation. One farm showed a very low count on violet red bile agar and a complete absence of positive presumptive coliform tests, irrespective of both total colony count and temperature. This result was most surprising in view of the high proportion of unsatisfactory rinses from this installation. With another farm, 50% of the total count on all the differential media used, was on the violet red bile agar, whereas at higher circulated solution temperatures this proportion dropped to less than 20%.

The use of Yeastrel milk agar with added crystal violet showed that there was no regular pattern in the incidence of Gram-negative organisms with increasing temperature. Whilst one installation, in spite of unsatisfactory colony counts, had a low count on this medium, other installations which had consistently high bacteriological standards had either very low, or nil, counts on this agar

It was noted that the incidence of thermoduric organisms increased slightly with the rising temperature of circulation. That this can be related with the efficiency of cleaning is pointed out by Thomas, Griffiths, Davies and Bebbington (1952) who found that washing in hot detergent could result in a partial selective sterilisation, the heat labile organisms being very largely destroyed and the greater proportion of the residual bacteria were thermoduric. The proportion of thermoduric organisms in relation to the total colony count varied more between different installations than as a result of different temperatures of the circulating detergent solution.

Sporeforming organisms increased slightly as the temperature of the circulating solution rose, but their relative occurrence remained constant over the temperature range examined.

The relationship was less well defined between the effect of circulation temperature of detergent solution and the composition of the bacterial flora than between different installations. The use of selective media permitted the incidence of different groups of organisms to be examined in relation to different circulating temperatures and different installations. There was a greater diversity of bacterial types in high rinse counts than where the rinse counts were low. High rinse counts were usually found with low temperature circulations Whilst the use of selective media permitted the enumeration of different groups of bacteria, it was found that the use of some were of limited use in the absence of further diagnostic tests. Mannitol salt agar and violet red bile agar are examples of such media. The results of using Yeastrel milk agar with the addition of crystal violet for the enumeration of Gram-negative organisms were found to be too variable in this investigation to permit any conclusion to be drawn.

Relationship between the temperature of circulation
Relationship between the temperature of circulation
and the bacterial flora of rinses of cleansed pipelines.

With a low (40°F) temperature of circulation the microflora appeared to be quite diverse. With the exception of coliform organisms, the groups which were identified, each constituted about 10% of the total. Milk souring types decreased with increasing temperatures. At higher temperatures micrococci and corynebacteria were the dominant groups. These results, with reference to low count rinses, agree with those obtained by other workers who investigated the bacterial flora of farm dairy equipment. Thomas (1964) who reported surveys on 76 bucket type and 20 pipeline milking systems, found that the microflora of efficiently cleaned equipment was dominated by micrococci with corynebacteria and aerobic sporeformers present. Similar results were found by Thomas, Hobson and Elson (1964) when examining the flora of equipment other than pipeline milkers cleansed by chemicals, and Edgell and Widdas (1964) with pipelines cleaned by circulation cleaning and caustic flooding.

There was a variation in the incidence of heat labile types even at higher temperatures noted at different installations. Where the cleaning was performed in a uniform standard method as confirmed by a consistently high standard of hygiene, the composition of the bacterial flora exhibited comparatively little change. Even where the standard of hygiene was consistently poor, there appeared to be a degree of uniformity in the composition of the flora, although there was a greater number of different groups, and with high count rinses there was a greater variation between installations than in the same installation with rinses taken at different times. Variations did occur at individual installations as a result of alterations in cleansing techniques either by the use of different circulation temperatures or by employing different detergents. It would seem, however, that a combination of the various factors at one installation produces an environment which encourages the development of a particular bacterial flora. Such a flora would remain constant so long as the cleansing techniques remain constant. Where the producer is made aware that the bacteriological quality of the installation is unsatisfactory, the cleansing operations will tend to be changed, in an effort to improve the results. Such modifications will tend to change the microflora. Different investigators have directed attention to the fact that the activity, and hence the composition, of the flora is not necessarily related to the size of the total colony count. Thomas (1964) showed that of 142 rinses of unsterile equipment 83 had a flora dominated by active milk souring and peptonizing types, and the other 59 were dominated by inactive types of bacteria. Thomas, Druce, Hobson and Makinson (1964) found that 18 out of 27 pipeline rinsing giving colony counts of more than $10^6/ft^2$ were shown to have a flora dominated by inactive types of bacteria which did not form any reaction in litmus milk within 72 hours at 22°C. In an investigation of the bacterial flora of pipelines sterilised by sodium hypochlorite, Thomas *et al.* (1963a) noted that one installation, cleansed by the circulation of a detergent/steriliser at a temperature of 130-140°F was shown to have a flora dominated by a culture resembling *Streptococci* var. *liquifaciens* and this was shown in every rinse taken over a period of nine months. By replacing all the rubber parts and by circulating at a higher temperature of 180°F this organism was eradicated. Conversely, the flora of one installation examined in the investigation reported by the author was found to be free from coliform contamination irrespective of the temperature of circulation and the size of the total colony count. 47% of the rinses examined from this farm had a count greater than the satisfactory level of 50,000 colonies/ft^2 so that it would be anticipated that coliforms would be present. On no occasion was a positive presumptive coliform test recorded so that it would appear that conditions created by this installation either prevented or inhibited the proliferation of this group of organisms.

Table 6 Total colony count on Yeastrel milk agar of pipeline rinses in relation to maximum initial temperature of circulating detergent

Farm	Temperature of detergent solution (°F)	Average count/ft²	Range of Total count	Number of Rinses	
A	140	187000	31000 - 677600	6	
	150	241000	67700 - 388000	19	
	160	136000	700 - 467600	22	
	170	32900	2400 - 05400	16	
	180	11400	700 - 28200	13	76
B	140	10850	4500 - 174200	2	
	150	132500	75000 - 190000	5	
	160	35500	16000 - 87400	6	
	170	2600		1	14
C	120	100600		1	
	130	262000	84700 - 440600	4	
	140	180200		1	
	150	218100	96500 - 397800	6	
	160	145000	14300 - 277300	4	
	170	35700	6800 - 85400	3	19
D	140	350000	24700 - 376000	6	
	150	124000	7400 - 204700	9	
	160	42000	27400 - 87100	3	18
E	140	51500	28700 - 74200	6	
	150	19100	2100 - 40600	3	
	160	4500		1	10
F	140	8500	4900 - 14100	2	
	150	4100	2900 - 5300	2	4
G	160	4700	2000 - 7500	3	
	170	4000		1	3
H	140	7500		1	
	150	4700		1	2

Table 7 **Total colony count on Yeastrel milk agar of pipeline rinses in relation to maximum final temperature of circulating detergent**

Farm	Temperature of detergent solution (°F)	Average count/ ft^2	Range of Total count	Number of Rinses	
A	110	235000	65000 - 366000	6	
	120	221800	29400 - 677600	12	
	130	54200	700 - 224000	16	
	140	28800	2400 - 740000	17	
	150	29200	9900 - 60000	17	
	160	20200	7500 - 39000	8	76
B	110	180500		1	
	120	92500	4500 - 190000	5	
	130	44200	4600 - 87400	7	
	140	12300		1	14
C	120	290500	14100 - 440000	2	
	130	204000	61200 - 440600	7	
	140	173000	6800 - 397600	8	
	160	11000	8400 - 13600	2	19
D	130	251200	81000 - 376000	7	
	140	35700	24700 - 263000	9	
	150	41100	7400 - 74600	2	18
E	130	43100	28700 - 74200	5	
	140	21000	8000 - 47000	5	10
F	130	6300	2900 - 14100	4	4
G	160	4500	2000 - 7500	3	3
H	130	6100	4700 - 7500	2	2

Table 8(a) Relationship between the total colony count and different groups of bacteria of farm pipelines washed by circulation cleaning

FARM A

Type of organism	Total colony count/ft^2 on Yeastrel milk agar: Less than 2.5×10^3	2.5×10^3-10^6	More than 1×10^6
Lactobacilli	21700 (32.5)	22000 (32.7)	18400 (25.6)
Staphylococci	26100 (39.1)	28900 (42.9)	34700 (48.4)
Coliforms	1300 (2.0)	1500 (2.2)	2200 (3.1)
Gram -ve bacteria	2100 (3.1)	3400 (5.1)	7200 (10.0)
Spores	7100 (10.6)	4300 (8.4)	3800 (5.3)
Thermoduric bacteria	8500 (12.7)	7200 (10.7)	5900 (8.2)
MacConkey Broth (%)	0	0	0
Milk souring organisms (%)	0	20	60

The figure in parenthesis is the count expressed as a percentage of the total count obtained by all the selective media.

Table 8(b) Relationship between the total colony count and different groups of bacteria of farm pipelines washed by circulation cleaning

FARM B

Type of organism	Total colony count/ft^2 on Yeastrel milk agar: Less than 2.5×10^3	$2.5 \times 10^3 - 10^6$	More than 1×10^6
Lactobacilli	22700 (67.0)	24800 (59.9)	27600 (56.9)
Staphylococci	850 (2.5)	2400 (5.8)	4700 (9.7)
Coliforms	3400 (10.2)	6500 (15.7)	7700 (15.9)
Gram -ve bacteria	6500 (19.4)	7100 (17.2)	8150 (16.8)
Spores	0	500 (1.2)	300 (0.6)
Thermoduric bacteria	300 (0.9)	100 (0.3)	100 (0.2)
MacConkey Broth (%)	0	50	70
Milk souring organisms (%)	0	60	70

The figure in parenthesis is the count expressed as a percentage of the total count obtained by all the selective media.

Table 8(c) Relationship between the total colony count and different groups of bacteria of farm pipelines washed by circulation cleaning

Farm C

Type of organism	Total colony count/ft^2 on Yeastrel milk agar: Less than 2.5×10^3	2.5×10^3-10^6	More than 1×10^6
Lactobacilli	2900 (42.7)	1700 (27.6)	1050 (17.4)
Staphylococci	1400 (20.6)	1800 (29.3)	1900 (31.4)
Coliforms	800 (11.8)	1100 (17.9)	1200 (19.4)
Gram -ve bacteria	900 (13.2)	1150 (18.7)	1350 (23.4)
Spores	200 (2.9)	100 (1.6)	0
Thermoduric bacteria	600 (8.8)	300 (4.9)	500 (9.1)
MacConkey Broth (%)	25	60	100
Milk souring organisms (%)	0	100	100

The figure in parenthesis is the count expressed as a percentage of the total count obtained on all the selective media.

Table 8(c)(ii) Relationship between the total colony count and different groups of bacteria of farm pipelines washed by circulation cleaning

FARM C - cold circulation of iodophor

Type of organism	Total colony count/ft^2 on Yeastrel milk agar Less than 2.5×10^3	2.5×10^3-10^6	More than 1×10^6
Lactobacilli		1600 (16.7)	1400 (12.9)
Staphylococci		3500 (36.5)	3480 (32.2)
Coliforms		3500 (36.5)	4750 (43.9)
Gram -ve bacteria		980 (10.2)	1190 (11.0)
Spores		0	0
Thermorudic bacteria		0	0
MacConkey Broth (%)		75	100
Milk souring organisms (%)		75	100

The figure in parenthesis is the count expressed as a percentage of the total count obtained by all the selective media.

Table 8(d) <u>Relationship between the total colony count and different groups of bacteria of farm pipelines washed by circulation cleaning</u>

FARM D

Type of organism	Total colony count/ft^2 on Yeastrel milk agar Less than 2.5×10^3	$2.5 \times 10^3 - 10^6$	More than 1×10^6
Lactobacilli	5900 (59.6)	3800 (39.0)	3700 (40.2)
Staphylococci	400 (4.0)	1400 (15.1)	1400 (15.2)
Coliforms	0	350 (3.8)	500 (5.4)
Gram -ve bacteria	1000 (10.1)	1650 (17.7)	2100 (22.8)
Spores	600 (6.1)	600 (6.5)	700 (9.6)
Thermoduric bacteria	2000 (20.2)	1500 (16.1)	800 (9.0)
MacConkey Broth (%)	20	40	60
Milk souring organisms (%)	0	50	75

The figure in parenthesis is the count expressed as a percentage of the total count obtained by all the selective media.

Table 8(e) Relationship between the total colony count and different groups of bacteria of farm pipelines washed by circulation cleaning

FARM E

Type of organisms	Total colony count/ft^2 on Yeastrel milk agar: Less than 2.5×10^3	2.5×10^3-10^6	More than $1. \times 10^6$
Lactobacilli	4500 (60.4)	2300 (36.2)	1500 (30.0)
Staphylococci	350 (5.9)	700 (11.2)	1000 (15.9)
Coliforms	100 (1.3)	1150 (18.2)	1400 (22.2)
Gram -ve bacteria	1800 (24.2)	1200 (18.5)	1300 (20.6)
Spores	600 (8.1)	400 (6.3)	200 (3.2)
Thermoduric bacteria	100 (1.3)	500 (7.9)	900 (14.3)
MacConkey Broth (%)	0	60	80
Milk souring organisms (%)	0	60	100

The figure in parehthesis is the count expressed as a percentage of the total count obtained by all the selective media.

Table 8(f) Relationship between the total colony count and different groups of bacteria of farm pipelines washed by circulation

FARM F

Type of organism	Total colony count/ft^2 on Yeastrel milk agar: Less than 2.5×10^3	$2.5 \times 10^3 - 10^6$	More than 1×10^6
Lactobacilli	1200 (65.9)	1200 (74.1)	1000 (73.5)
Staphylococci	20 (1.1)	20 (1.2)	40 (2.9)
Coliforms	200 (11.0)	200 (12.3)	170 (12.5)
Gram -ve bacteria	100 (5.5)	100 (6.2)	50 (3.7)
Spores	100 (5.5)	0	0
Thermoduric bacteria	200 (11.0)	100 (6.2)	100 (7.4)
MacConkey Broth (%)	0	0	0
Milk souring organisms (%)	0	0	0

The figure in parenthesis is the count expressed as a percentage of the total count obtained by all the selective media.

Table 8(g) Relationship between the total colony count and different groups of bacteria of farm pipelines washed by circulation cleaning

FARM G

	Total colony count/ft^2 on Yeastrel milk agar		
Type of organism	Less than 2.5×10^3	2.5×10^3-10^6	More than 1×10^6
Lactobacilli	600 (38.5)		
Staphylococci	60 (3.9)		
Coliforms	15 (1.0)		
Gram-ve bacteria	45 (3.0)		
Spores	150 (9.6)		
Thermoduric bacteria	700 (44.9)		
MacConkey Broth (%)	0		
Milk souring organisms (%)	0		

The figure in parenthesis is the count expressed as a percentage of the total count obtained by all the selective media.

Table 8(h) Relationship between the total colony count and different groups of bacteria of farm pipelines washed by circulation cleaning

Farm H

Type of organism	Total colony count/ft^2 on Yeastrel milk agar: Less than 2.5×10^3	$2.5 \times 10^3-10^6$	More than 1×10^6
Lactobacilli	2700 (49.6)		
Staphylococci	350 (6.4)		
Coliforms	620 (13.5)		
Gram -ve bacteria	1050 (19.3)		
Spores	50 (0.9)		
Thermoduric bacteria	550 (10.5)		
MacConkey Broth (%)	0		
Milk souring organisms	0		

The figure in parenthesis is the count expressed as a percentage of the total count obtained by all the selective media.

Table 9(a) The effect of temperature of circulating detergent on the bacterial count of the pipeline

FARM A

count/ml initial rinse

Temperature (°F) (°C)	140 60	150 66	160 71	170 77	180 82
Lactobacilli	21360 (21.8)	19200 (23.8)	16730 (16.2)	20100 (25.5)	22100 (30.2)
Staphylococci	45280 (46.1)	48300 (59.9)	39800 (38.3)	37400 (47.5)	31000 (42.4)
Coliforms	1980 (1.9)	2530 (3.2)	3000 (2.9)	3100 (3.9)	1700 (2.3)
Gram -ve bacteria	7200 (7.3)	2210 (2.4)	31200 (30.0)	2810 (4.5)	3100 (4.2)
Spores	4320 (4.4)	4200 (5.2)	6000 (5.7)	6700 (5.7)	6500 (8.9)
Thermoduric bacteria	18060 (18.4)	4200 (5.2)	7200 (6.9)	8600 (10.9)	8800 (12.1)
MacConkey Broth (%)	0	0	0	0	0
Milk souring organisms (%)	46	20	0	0	0
Total colony count/ft^2 x 10^2	1870	2410	1366	329	114
No. of rinses examined	6	19	22	16	3

The figure in parenthesis is the count expressed as a percentage of the total count obtained by all the selective media.

Table 9(b) The effect of temperature of circulating detergent on the bacterial count of the pipeline

FARM B

count/ml initial rinse

Temperature (°F) (°C)	140 60	150 66	160 71	170 77	180 82
Lactobacilli	2800 (17.2)	19000 (47.7)	25200 (69.2)	26400 (63.7)	
Staphylococci	4500 (27.6)	4150 (10.5)	870 (2.4)	900 (2.2)	
Coliforms	7500 (46.1)	7800 (19.6)	1200 (3.4)	7700 (18.6)	
Gram -ve bacteria	1340 (8.2)	8500 (21.4)	8310 (22.8)	6100 (11.7)	
Spores	200 (1.2)	400 (1.0)	700 (1.9)		
Thermoduric bacteria	0	0	150 (0.4)	300 (2.7)	
MacConkey Broth (%)	50	80	60	0	
Milk souring organisms (%)	50	80	40	20	
Total colony count/ft^2 x 10^2	108	1325	355	26	
No. of rinses examined	2	5	6	1	

The figure in parenthesis is the count expressed as a percentage of the total count obtained by all the selective media.

Table 9(c) The effect of temperature of circulating detergent on the bacterial count of the pipeline

FARM C
count/ml initial rinse

Temperature (°F) (°C)	120	130	140 60	150 66	160 71	170 77
Lactobacilli	1420 (29.7)	1520 (22.3)	1600 (28.6)	2700 (36.0)	2900 (41.4)	2400 (39.4)
Staphylococci	1600 (33.0)	1900 (27.9)	1800 (25.5)	2100 (28.0)	1700 (24.3)	1300 (21.3)
Coliforms	600 (12.5)	1300 (19.1)	1000 (17.9)	1100 (14.7)	700 (10.0)	700 (11.4)
Gram-ve bacteria	860 (17.9)	1400 (20.5)	950 (16.9)	1100 (14.7)	900 (12.9)	900 (14.8)
Spores	100 (2.1)	100 (1.5)	0	100 (1.3)	200 (2.9)	200 (3.3)
Thermoduric bacteria	200 (3.3)	600 (.8.7)	350 (9.9)	400 (5.3)	600 (8.6)	600 (9.8)
MacConkey Broth (%)	100	50	100	17	25	0
Milk souring organisms (%)	100	25	100	34	0	0
Total colony count/ft^2 x 10^2	1006	2620	1802	2181	1450	357
No. of rinses examined	1	4	1	6	4	3

The figure in parenthesis is the count expressed as a percentage of the total count obtained by all the selective media.

Table 9(d) The effect of the temperature of the circulating detergent on the bacterial count of the pipeline

FARM D

count/ml initial rinse

Temperature (°F) (°C)	140 60	150 66	160 71
Lactobacilli	1200 (21.4)	5300 (55.8)	4100 (47.4)
Staphylococci	450 (8.0)	350 (3.6)	400 (4.6)
Coliforms	300 (5 3)	350 (3.6)	100 (1.2)
Gram-ve bacteria	1590 (26.2)	1200 (12.6)	1500 (17.3)
Spores	500 (8.9)	600 (6.3)	600 (7.2)
Thermoduric bacteria	1570 (22.2)	1700 (17.9)	1950 (17.9)
MacConkey Broth (%)	50	30	30
Milk souring organisms (%)	80	20	0
Total colony count/ft^2 x 10^2	3500	1240	420
No. of rinses examined	6	9	3

The figure in parenthesis is the count expressed as a percentate of the total count obtained by all the selective media.

Table 9(e) The effect of temperature of the circulating detergent on the bacterial count of the pipeline

FARM E

count/ml initial rinse

Temperature (°F) (°C)	140 60	150 66	160 71
Lactobacilli	1500 (25.6)	2000 (34.2)	4100 (56.8)
Staphylococci	980 (17.2)	540 (9.2)	250 (3.5)
Coliforms	1140 (19.6)	970 (16.5)	70 (1.0)
Gram -ve bacteria	1200 (20.6)	1340 (22.9)	2200 (30.5)
Spores	300 (5.5)	300 (5.1)	500 (6.8)
Thermoduric bacteria	700 (12.0)	700 (11.9)	100 (1.3)
MacConkey Broth (%)	80	60	0
Milk souring organisms (%)	100	60	0
Total colony count/ft^2 x 10^2	515	191	45
No. of rinses examined	6	3	1

The figure in parenthesis is the count expressed as a percentage of the total count obtained by all the selective media.

Table 9(f) <u>The effect of temperature of the circulating detergent on the bacterial count of the pipeline</u>

FARM F

count/ml initial rinse

Temperature (^{o}F) (^{o}C)	140 60	150 66
Lactobacilli	1100 (73.3)	1200 (65.9)
Staphylococci	40 (2.7)	20 (1.1)
Coliforms	170 (11.3)	200 (10.9)
Gram-ve bacteria	90 (6.0)	100 (5.5)
Spores	0	100 (5.5)
Thermoduric bacteria	100 (6.6)	200 (10.9)
MacConkey Broth (%)	0	0
Milk souring organisms (%)	0	0
Total colony count/ft^2 x 10^2	85	41
No. of rinses examined	2	2

The figure in parenthesis is the count expressed as a percentage of the total count obtained by all the selective media.

Table 9(g) The effect of temperature of circulating detergent on the bacterial count of the pipeline

FARM G

count/ml initial rinse

Temperature (°F) (°C)	140 60	150 66
Lactobacilli	700 (43.2)	500 (34.0)
Staphylococci	40 (2.5)	70 (4.8)
Coliforms	20 (1.2)	0
Gram -ve bacteria	60 (3.7)	0
Spores	100 (6.2)	300 (20.4)
Thermoduric bacteria	700 (43.2)	600 (40.8)
MacConkey Broth (%)	0	0
Milk souring organisms (%)	0	0
Total colony count/ft^2 x 10^2	47	40
No. of rinses examined	3	1

The figure in parenthesis is the count expressed as a percentage of the total count obtained by all the selective media.

Table 9(h) <u>The effect of temperature of the circulating detergent on the Bacterial count of the pipeline</u>

FARM H

count/ml initial rinse

Temperature (^oF) (^oC)	140 60	150 66
Lactobacilli	27000 (91.2)	27000 (91.1)
Staphylococci	410 (1.4)	300 (1.0)
Coliforms	710 (2.4)	530 (1.8)
Gram -ve bacteria	1100 (3.8)	1000 (3.4)
Spores	0	100 (0.3)
Thermoduric bacteria	400 (1.4)	700 (2.3)
MacConkey Broth (%)	0	0
Milk souring organisms (%)	0	0
Total colony count/ft^2 x 10^2	75	47
No. of rinses examined	1	1

The figure in parenthesis is the count expressed as a percentage of the total count obtained by all the selective media.

Table 10 Relationship between certain types of bacteria and the total colony count of farm pipeline rinses

Total of 8 installations investigated

Type of organism	Total colony count/ft^2 on Yeastrel milk agar					
	Less than 2.5×10^3		2.5×10^3-10^6		More than 1×10^6	
	No. of isolates	(%)	No. of isolates	(%)	No. of isolates	(%)
Micrococci	303	36.0	207	22.7	219	18.4
Corynebacteria	268	31.8	241	26.5	219	18.4
Other Gram +ve rods	93	11.1	108	11.9	134	11.3
Streptococci	38	4.6	90	9.9	123	10.3
Staphylococci	51	6.1	105	11.5	197	16.6
Gram -ve rods: proteolytic	26	3.1	69	7.6	125	10.5
Gram -ve rods: non-proteolytic	52	6.2	70	7.7	110	9.3
Coliforms	8	1.0	18	2.0	49	4.1
Others	3	0.4	3	0.3	14	1.2
Total	842		911		1190	

Table 10(a) Relationship between certain types of bacteria and the total colony count of farm pipeline rinses

FARM A

Type of organism	Total colony count/ft^2 on Yeastrel milk agar					
	Less than 2.5×10^3		$2.5 \times 10^3 - 10^6$		More than 1×10^6	
	No. of isolates	(%)	No. of isolates	(%)	No. of isolates	(%)
Micrococci	154	34.2	132	27.5	135	23.5
Corynebacteria	187	41.5	175	36.5	170	29.6
Other Gram +ve rods	44	9.7	47	9.8	52	9.0
Streptococci	7	1.7	19	3.9	22	3.8
Staphylococci	35	7.7	60	12.6	120	20.9
Gram -ve rods: proteolytic	6	1.4	19	3.9	29	5.0
Gram -ve rods: non-proteolytic	13	3.0	25	5.2	35	6.0
Coliforms	3	0.3	2	0.4	8	1.3
Others	1	0.2	2	0.4	4	0.7
Total	450		481		575	

Table 10(b) Relationship between certain types of bacteria and the total colony count of farm pipeline rinses

FARM 8

Type of organism	Total colony count/ft^2 on Yeastrel milk agar: Less than 2.5×10^3		$2.5 \times 10^3 - 10^6$		More than 1×10^6	
	No. of isolates	(%)	No. of isolates	(%)	No. of isolates	(%)
Micrococci	61	67.7	31	31	23	25.5
Corynebacteria	10	11.1	24	24	16	17.7
Other Gram +ve rods	7	7.7	22	22	12	13.3
Streptococci	2	2.2	5	5	6	6.6
Staphylococci	3	3.3	6	6	8	8.8
Gram -ve rods: proteolytic	1	1.1	7	7	15	16.6
Gram -ve rods: non-proteolytic	4	4.4	3	3	4	4.4
Coliforms	1	1.1	2	2	6	6.6
Others	1	1.1	0		0	
Total	90		100		90	

Table 10(c) Relationship between certain types of bacteria and the total colony count of farm pipeline rinses

FARM C

Type of organisms	Total colony count/ft^2 on Yeastrel milk agar					
	Less than 2.5×10^3		$2.5 \times 10^3 - 10^6$		More than 1×10^6	
	No. of isolates	(%)	No. of isolates	(%)	No. of isolates	(%)
Micrococci	8	13.3	9	11.3	14	15.5
Cornybacteria	6	10	7	8.7	6	6.6
Other Gram +ve rods	16	26.7	14	17.5	18	20.0
Streptococci	17	28.3	22	27.5	19	21.1
Staphylococci	10	16.7	11	13.7	11	12.2
Gram -ve rods; proteolytic	2	3.3	6	7.5	8	7.9
Gram -ve rods; non-proteolytic	1	1.6	8	10	6	6.6
Coliforms	0		2	2.5	5	5.5
Others	0		1	1.2	3	3.3
Total	60		80		90	

Table 10(c)(ii) Relationship between certain types of bacteria and the total colony count of farm pipeline rinses

FARM C

(circulation of a cold iodophor solution)

Type of organism	Total colony count/ft^2 on Yeastrel milk agar					
	Less than 2.5×10^3		$2.5 \times 10^3-10^6$		More than 1×10^6	
	No. of isolates	(%)	No. of isolates	(%)	No. of isolates	(%)
Micrococci			17	21.3	10	6.3
Corynebacteria			1	1.3	2	1.3
Other Gram +ve rods			2	2.5	17	10.7
Streptococci			24	30.0	41	25.6
Staphylococci			14	17.5	31	19.3
Gram -ve rods; proteolytic			8	10.0	18	11.5
Gram -ve rods; non-proteolytic			12	15.0	21	13.2
Coliforms			2	2.5	17	10.7
Others					3	1.8
Total			80		160	

Table 10(d) Relationship between certain types of bacteria and the total colony count of farm pipeline rinses

FARM D

Type of organisms	Total colony count/ft^2 on Yeastrel milk agar: Less than 2.5×10^3		2.5×10^3–10^6		More than 1×10^6	
	No. of isolates	(%)	No. of isolates	(%)	No. of isolates	(%)
Micrococci	37	37	18	18	14	9.5
Corynebacteria	29	29	20	20	13	8.6
Other Gram +ve rods	6	6	9	9	28	18.6
Streptococci	0	0	9	9	17	11.5
Staphylococci	0	0	4	4	7	3.6
Gram -ve rods; proteolytic	12	12	21	21	35	23.3
Gram -ve rods; non-proteolytic	12	12	13	13	27	18.0
Coliforms	4	4	6	6	5	3.3
Others	0	0			3	2.0
Total	100		100		100	

Table 10(e) Relationship between certain types of bacteria and the total colony count of farm pipeline rinses

FARM E

Type of organism	Total colony count/ft^2 on Yeastrel milk agar					
	Less than 2.5×10^3		2.5×10^3-10^6		More than 1×10^6	
	No of isolates	(%)	No. of isolates	(%)	No. of isolates	(%)
Micrococci	12	60	9	22.5	11	13.8
Corynebacteria	3	15	4	10	8	10
Other Gram +ve rods	1	0.5	8	20	10	12.2
Streptococci	3	1.5	4	10	12	15
Staphylococci	0	0	3	7.5	9	11.1
Gram -ve rods: proteolytic	0	0	3	7.5	8	10
Gram -ve rods; non-proteolytic	1	0.5	7	17.5	15	18.8
Coliforms	0	0	2	5.0	6	7.5
Others	0	0	0	0	1	1.3
Total	20		40		80	

Table 10(f) Relationship between certain types of bacteria and the total colony count of farm pipeline rinses

FARM F

Type of organism	Total colony count/ft^2 on Yeastrel milk agar: Less than 2.5×10^3		$2.5 \times 10^3 - 10^6$		More than 1×10^6	
	No. of isolates	(%)	No. of isolates	(%)	No. of isolates	(%)
Micrococci	17	42.5	17	28.3	12	20
Corynebacteria	9	22.5	10	16.6	4	6.6
Other Gram +ve rods	4	10	8	13.3	9	15
Streptococci	2	5	9	11.3	8	13.3
Staphylococci	1	2.5	7	8.8	11	18.3
Gram -ve rods; proteolytic	2	5	5	6.3	12	20
Gram -ve rods; non-proteolytic	5	12.5	2	3.3	2	3.3
Coliforms	0		2	3.3	2	3.3
Others	0		0		0	
Total	40		60		60	

Table 10(g) Relationship between certain types of bacteria and the total colony count of farm pipeline rinses

FARM G

Type of organism	Total colony count/ft^2 on Yeastrel milk agar: Less than 2.5×10^3		2.5×10^3-10^6		More than 1×10^6	
	No. of isolates	(%)	No. of isolates	(%)	No. of isolates	(%)
Micrococci	17	27.2				
Corynebacteria	12	20				
Other Gram +ve rods	10	16.7				
Streptococci	6	10				
Staphylococci	2	3.3				
Gram -ve rods; proteolytic	3	3.8				
Gram -ve rods; non-proteolytic	9	15				
Coliforms	0					
Others	1	1.7				
Total	60					

Table 10(h) Relationship between certain types of bacteria and the total colony count of farm pipeline rinses

FARM H

Type of organism	Total colony count/ft^2 on Yeastrel milk agar: Less than 2.5×10^3 No. of isolates	(%)	2.5×10^3–10^6 No. of isolates	(%)	More than 1×10^6 No. of isolates	(%)
Micrococci	14	35				
Corynebacteria	12	30				
Other Gram +ve rods	6	15				
Streptococci	1	2.5				
Staphylococci	0					
Gram -ve rods; proteolytic	0					
Gram -ve rods; non-proteolytic	7	17.5				
Coliforms	0					
Others	0					
Total	40					

Table II Relationship of the incidence of certain types of bacteria with different temperatures of circulated detergent

Average of eight installations examined

Temperature °F °C	140 60	150 66	160 71	170 77	
	No.of isolates (%)	No.of isolates (%)	No.of isolates (%)	No.of isolates (%)	No.of isolates (%)
Micrococci	89 (17.7)	210 (25.3)	227 (31.8)	107 (26.9)	88 (34.1)
Corynebacteria	69 (13.7)	172 (20.7)	187 (26.2)	158 (40.0)	174 (44.2)
Other Gram +ve rods	70 (14.0)	101 (12.2)	92 (12.9)	47 (11.8)	28 (10.9)
Streptococci	59 (11.7)	55 (6.6)	58 (8.1)	15 (3.8)	6 (2.3)
Staphylcocci	66 (13.1)	142 (17.1)	60 (8.2)	32 (8.0)	12 (4.5)
Gram -ve rods; proteolytic	69 (13.7)	56 (6.7)	38 (5.3)	12 (3.0)	3 (1.2)
Gram -ve rods; non-proteolytic	55 (11.0)	72 (8.7)	43 (6.0)	19 (4.8)	6 (2.3)
Coliforms	24) 4.8)	19 (1.9)	5 (0.7)	0	0
Others	3 (0.6)	3 (0.3)	5 (0.7)	8 (2.0)	1 (0.4)
TOTAL	504	830	715	398	258

Table 11 Relationship of the incidence of certain types of bacteria with different temperature of circulated detergent

FARM A

Temperature (°F)	140		150		160		170		180	
	No.of iso-lates	(%)	No.of iso-lates	(%)	No.of iso-lates	(%)	No.of iso-lates	(%)	No.of iso-lates	(%)
Micrococci	28	(24.4)	90	(23.7)	127	(29.2)	88	(27.7)	88	(34.1)
Corynebacteria	31	(26.9)	97	(25.6)	149	(34.3)	141	(44.0)	174	(44.2)
Other Gram +ve rods	9	(7.8)	32	(8.4)	44	(10.1)	30	(9.4)	28	(10.9)
Streptococci	6	(5.2)	12	(3.2)	16	(3.7)	8	(2.5)	6	(2.3)
Staphylcocci	27	(23.5)	103	(27.2)	46	(10.6)	27	(8.9)	12	(4.5)
Gram -ve rods; proteolytic	6	(5.2)	14	(3.7)	21	(4.8)	10	(3.1)	3	(1.2)
Gram -ve rods; non proteolytic	4	(3.5)	27	(8.9)	26	(6.0)	10	(3.1)	6	(2.3)
Coliforms	4	(3.5)	5	(1.0)	4	(1.2)	0		0	
Others	0		0		2	(0.5)	4	(1.3)	1	(0.4)
TOTAL	115		380		435		318		258	

Table 11(b) Relationship of the incidence of certain types of bacteria with different temperature of circulated detergent

FARM B

Temperature(^{o}F)	140		150		160		170	
	No.of iso-lates	(%)	No.of iso-lates	(%)	No.of iso-lates	(%)	No.of iso-lates	(%)
Micrococci	11	(27.3)	34	(34.0)	63	(52.5)	7	(35.0)
Corynebacteria	6	(15.0)	19	(18.0)	18	(15.0)	7	(35.0)
Other Gram +ve rods	3	(7.5)	18	(18.0)	17	(14.2)	3	(15.0)
Streptococci	3	(7.5)	6	(6.0)	4	(0.3)	0	
Staphylcocci	6	(15.0)	5	(5.0)	6	(0.5)	0	
Gram -ve rods; proteolytic	7	(17.5)	8	(8.0)	7	(0.5)	1	(5.0)
Gram -ve rods; non-proteolytic	1	(0.3)	5	(5.0)	3	(0.3)	2	(10.0)
Coliforms	3	(0.8)	5	(5.0)	1	(0.1)	0	
Others	0		0		1	(0.1)	0	
TOTAL	40		100		120		20	

Table 11(c) <u>Relationship of the incidence of certain types of bacteria with different temperature of circulated detergent</u>

FARM C

Temperature (^{o}F)	140		150		160		170	
	No.of iso-lates	(%)	No.of iso-lates	(%)	No.of iso-lates	(%)	No.of iso-lates	(%)
Micrococci	4	(20.0)	6	(8.5)	15	(15.0)	6	(15.0)
Corynebacteria	2	(10.0)	4	(5.7)	9	(9.0)	4	(10.0)
Other Gram +ve rods	0		13	(16.5)	25	(25.0)	10	(25.0)
Streptococci	3	(15.0)	17	(24.3)	33	(33.0)	5	(12.5)
Staphylococci	4	(20.0)	17	(24.3)	6	(6.0)	5	(12.5)
Gram -ve rods; proteolytic	1	(5.0)	7	(10.0)	7	(7.0)	1	(2.5)
Gram -ve rods; non-proteolytic	2	(10.0)	3	(4.3)	5	(5.0)	5	(12.5)
coliforms	4	(20.0)	3	(4.3)	0		0	
Others	0		0		0		4	(10.0)
TOTAL	20		70		100		40	

Table 11(d) Relationship of the incidence of certain types of bacteria with different temperature of circulated detergent

FARM D

Temperature (°F)	140		150	
	No.of iso-lates	(%)	No.of iso-lates	(%)
Micrococci	m14	(9.5)	31	(22.0)
Corynebacteria	13	(8.6)	24	(17.1)
Other Gram +ve rods	28	(18.6)	22	(15.7)
Streptococci	17	(11.5)	12	(8.5)
Staphylcocci	7	(3.6)	8	(5.7)
Gram -ve rods; proteolytic	35	(23.3)	17	(12.1)
Gram -ve rods; non proteolytic	27	(18.0)	21	(15.0)
Coliforms	5	(3.3)	2	(1.4)
Others	3	(2.0)	3	(2.1)
TOTAL	149		140	

Table 11(e) Relationship of the incidence of certain types of bacteria with different temperature of circulated detergent

FARM E

Temperature (^{o}F)	140		150		160	
	No. of iso-lates	(%)	No. of iso-lates	(%)	No. of iso-lates	(%)
Micrococci	7	(8.7)	14	(35.0)	11	(55.0)
Corynebacteria	3	(3.7)	7	(17.5)	5	(25.0)
Other Gram +ve rods	16	(20.0)	3	(7.5)	0	
Streptococci	16	(20.0)	2	(5.0)	1	(5.0)
Staphylcocci	11	(13.7)	1	(2.5)	0	
Gram -ve rods; proteolytic	8	(10.0)	3	(7.5)	-	
Gram -ve rods; non-proteolytic	13	(16.0)	8	(20.0)	2	(10.0)
Coliforms	6	(7.5)	2	(5.0)	0	
Others	0		0		1	(5.0)

Table 11(f) Relationship of the incidence of certain types of bacteria with different temperature of circulated detergent

FARM F

Temperature (°F)	140		150	
	No.of iso-lates	(%)	No.of iso-lates	(%)
Micrococci	20	(25.0)	26	(32.5)
Corynebacteria	9	(11.3)	14	(17.5)
Other Gram +ve rods	10	(12.5)	11	(13.7)
Streptococci	13	(16.3)	6	(7.5)
Staphylcocci	1	(13.7)	8	(10.0)
Gram -ve rods; proteolytic	12	(15.0)	7	(8.75)
Gram -ve rods; non proteolytic	3	(3.8)	6	(7.5)
Coliforms	2	(2.5)	2	(2.5)
Others	0		0	
TOTAL	80		80	

Table II(g) Relationship of the incidence of certain types of bacteria with different temperature of circulated detergent

FARM G

Temperature (^{o}F)	160		170	
	No. of isolates	(%)	No. of isolates	(%)
Micrococci	11	(27.5)	6	(30.0)
Corynebacteria	6	(15.0)	6	(30.0)
Other Gram +ve rods	6	(15.0)	4	(20.0)
Streptococci	4	(10.0)	2	(10.0)
Staphylcocci	2	(5.0)	0	
Gram -ve rods; proteolytic	3	(7.5)	0	
Gram -ve rods; non-proteolytic	7	(17.5)	2	(10.0)
Coliforms	0		0	
Others	1	(2.5)	0	
TOTAL	40		20	

Table 11(h) Relationship of the incidence of certain types of bacteria with different temperature of circulated detergent

FARM H

Temperature(^{o}F)	148		150	
	No.of iso-lates	(%)	No.of iso-lates	(%)
Micrococci	5	(25.0)	9	(45.0)
Corynebacteria	5	(25.0)	7	(35.0)
Other Gram +ve rods	4	(20.0)	2	(10.0)
Streptococci	1	(5.0)	0	
Staphylcocci	0		0	
Gram -ve rods; proteolytic	0		0	
Gram -ve rods; non proteolytic	5	(25.0)	2	(10.0)
Coliforms	0		0	
Others	0		0	
TOTAL	20		20	

THESIS SUMMARY

The increasing number of pipeline milking installations have indicated the necessity for a study of the different factors which influence the efficiency of cleansing. Due to the length of the pipeline circuits cleaning is carried out by circulatory methods, the cleaning and sterilising solutions being drawn through the pipeline circuit by the vacuum pump. The factors studied were those of time of circulation, temperature and composition of the cleansing solution and also the turbulence induced in it. These factors are inter-related and inter-dependent and in order to achieve satisfactorily cleansed equipment it is essential that cleansing is carried out at the optimum values of each factor for any particular installation. The determination of such optimum values can only be determined by trials at that installation, but others, such as turbulence of the detergent, are sub-dependent, and can therefore conform to general recommendations.

The correct design and installation of equipment is the prime necessity for the subsequent correct operation and cleansing. Whilst individual components have been designed for cleaning in place, inefficient installation does present cleaning hazards. With installations which incorporate considerable lengths of pipeline, the maintenance of the correct direction and magnitude of fall present considerable problems at the time of installation. The

slope of the pipeline affects vacuum fluctuations as a result of flooding the pipeline with milk or detergent and therefore it is essential that the correct fall be determined. The method of connecting together lengths of pipeline by means or rubber sleeves is not satisfactory and creates additional cleaning and sterilising problems. These are due to the porous nature of the rubber and the lack of continuity of the inner surface of the pipeline. It is suggested that alternative means of connecting pipeline be investigated.

The desirable temperature of circulating solutions has been given varying values by different workers. From results obtained in an investigation described in this study it would appear that the minimum temperature necessary to ensure satisfactorily cleansed equipment is 140°F (60°C). This temperature, being measured at the discharge end of the pipeline circuit, is that required when cleansing is being effected by the circulation of a detergent steriliser containing chlorine bearing compounds. The initial temperature necessary to achieve the required temperature at the outlet of the circuit would vary with several factors amongst which would be the length of the circuit and the material from which the pipeline is constructed. It has been demonstrated that due to the lower conduction characteristics of glass, pipelines made of this material would be more suitable for extended milk pipeline circuits and would assist in maintaining the temperature of the circulating solution. On the other hand, pipelines of this material have a greater heat capacity and for shorter pipeline circuits, such as milking parlours, stainless steel would be more suitable for the construction of the pipelines since less heat would be lost by conduction to the outside than would be absorbed by the pipeline itself.

The turbulence which is necessary for the effective removal of the soil from the pipeline is obtained by the operation of the vacuum pump, provided that this is adequate for the installation. This, however, is not always the case, the vacuum pump being inefficient in operation or of an inadequate capacity. The inadequacy of the vacuum pump is reflected in unsatisfactory cleansing.

It has been shown that corrosion problems are still existent in spite of the widespread use of stainless steel equipment. Work is described which shows that the sodium salt of ethylenediaminetetra-acetic acid can, under certain conditions, exhibit corrosive characteristics and can result in the products of corrosion being laid down in other parts of the installation. This defect, however, only takes place where galvanised pipelines or galvanised components are incorporated in the circuit when the corrosive products are deposited on the surface of the stainless steel milk pipeline.

The constituent compounds of detergents used for circulation cleaning systems are of much more importance than for detergents used for manual cleaning since reliance can only be placed on the chemical activity of the constituents and the physical effects of turbulence and temperature. Work is reported which shows that the effect of different detergent composition on cleaning efficiency is less than that of a higher - 140 to 170°F (60 to 75°C) - or lower - 110 to 140°F (45 to 60°C) - temperature. In view of the contribution towards cleaning efficiency which is made by the detergent constituents, either individually or collectively, it is felt that there is a need for further investigational work in order to relate detergent composition and constituents with cleaning efficiency, an aspect which has received but little attention and published work refers to results obtained by detergents the composition of which is rarely reported.

Many different techniques have been reported to determine the efficiency of the cleaning and the method most commonly adopted in the United Kingdom is the total bacterial count of a sterile rinse which had been passed through the cleansed pipeline circuit. Such a method, when strictly conforming to a standard technique, permits a determination which gives a comparative value between different rinses either of the same, or of different installations. Work is described which indicates that a particular installation develops a bacterial population of a regular composition which is only affected by changes either in the installation itself or in the system of cleaning. Whilst the magnitude rather than the composition, of the bacterial population is controlled by the efficiency of the cleansing, any improvement in the cleansing system would also affect the composition of the residual bacterial population.

Whilst the total number of bacteria is used as the criterion of cleaning efficiency it is felt that such bacteriological results would be of more value were the incidence of specific groups of organisms reported. Such information would have a more direct application on the final utilisation of the milk which would be affected by such infected equipment. This aspect is becoming of greater commercial importance in view of the refrigerated farm milk storage tanks coupled with the use of extended milk pipelines.

The necessary requirements of a cleaning system for a farm dairy pipeline are that it must be simple, economical to operate and efficient even with poor labour and possibly with limited hot water supplies and poor environmental conditions. Whilst it has been found possible to product milk of a satisfactory hygienic quality under such conditions, further investigational work is necessary to determine why similar results cannot be obtained regularly at all installations. Progress has been made with the cleansing of milking parlour installations but there appears to be room for improvement in the standards of hygiene achieved with extended milk pipeline systems, the cleaning of which presents different problems as yet not completely resolved.

Abd-el-Malek, Y. & Gibson, T. (1952). J. Dairy Res. 19, 294.

Adam, N.K. (1941). The Physics and Chemistry of Surfaces, 3rd Ed. London: Oxford University Press.

Akam, D.N. (1955). J. Soc. Dairy Technol. 8, 94.

Alexander, M.H., Nelson, W.O. & Ormiston, E.E. (1952). J. Dairy Sci. 35, 874.

Alexander, M.H., Nelson, W.O. & Ormiston, E.E. (1953). Proc. XIII Int. Dairy Cong. 2, 133.

Allum, M.J. (1964). Fd Mf. 39 (12), 39.

American Public Health Association (1953). Standard Methods for the Examination of Dairy Products 10th Ed. New York: A.P.H.A. Inc.

Anderson, R.M., Satanek, J. & Harris, J.C. (1959). J. Am. Oil Chem. So 36, 286.

Anderson, R.M., Satanek, J. & Harris, J.C. (1960). J. Am. Oil Chem. So 37, 119.

Ayrshire County Council, (1967). Personal communication Sept. 18th.

Bacon, D.C. & Smith, J.E. (1948). Ind. Engng Chem. Fundam. 40, 235.

Baines, S. (1962). Ann. Meeting, Scott. Milk Officers' Conference, Glasgow.

Baker, R.W.R. (1936). Biochem. J. 41, 337.

Bird, Elizabeth R. (1956). Proc. XIV Int. Dairy Cong. 3, 31.

Bird, Elizabeth R. (1957). N.A.A.S.q.Rev. 37, 112.

Botham, G.H. (1956). Chemy Ind. 42, 116.

Bourne, M.C. & Jennings, W. (1961). Fd Technol., Champaign 15, 495.

Bourne, M.C. & Jennings, W. (1963). J. Am. Oil Chem. Soc. 40, 523.

British Standard Specification (1955). 2598.

Bruce, J.M. (1959). Chemy Ind. 45, 860.

Burton, A.J. (1967). Process Engng (London) Aug, 10.

Calbert, H.E. (1953). Milk Pl. Mon. 42, 15.

Calbert, H.E. (1958). J. Milk Fd Technol. 21, 12.

Carriere, D.F.C., Glegg, L.F.L., Clough, P.A., Thiel, C.C., Akam, D.N. Gruber, M. & Hirons, Elisabeth (1953). J. Dairy Res. 22, 166.

Church, W.R. (1954). M.S. Thesis Mich. Sta. Univ. (Kline & Fox, 1966).

Claydon, T.J. (1953). J. Dairy Sci. 36, 391.

Clegg, L.F.L. (1955). J. appl. Bact. 18, 358.

Clegg, L.F.L. (1956). J. Soc. Dairy Technol. 9, 30.

Clegg, L.F.L. (1957). Dairy Inds. 22, 929.

Clegg, L.F.L. & Hoy, W.A. (1956). Unpublished data (Clegg, 1956).

Clough, P.A. (1964). Fmrs' Wkly 67, 99.

Clough, P.A. (1965). Fmrs' Wkly Buyer's Guide Supplement.

Clough, P.A. & Thiel, C.C. (1961). Agriculture, Lond. 68, 33.

Clough, P.A., Akam, D.N. & Cant, D. (1965). Esso Fmr 17, 4.

Cousins, Christina M. (1961). Agriculture, Lond. 68, 33.

Cousins, Christina M. (1963). J. appl. Bact. 26, 376.

Cousins, Christina M.(1967). J. Soc. Dairy Technol. 20, 198.

Cousins, Christina M., Clegg, L.F.L., Thiel, C.C., Jones, G.F. & Egdell, J.W. (1957). J. appl. Bact. 20, 158.

Cousins, Christina M. & McKinnon, C.H. (1962). Proc. XVI Int. Dairy Cong. A, 479.

Cousins, Christina, M., Hoy, W.A. & Clegg, L.F.L. (1960). J. appl. Bact. 23, 359.

Crossley, E.L. (1964). Proc. Soc. agric. Bact. 16.

Cucci, T. (1954). J. Milk Fd Technol. 20, 198.

Cuthbert, W.A. (1960). J. Soc. Dairy Technol. 13, 142.

Cuthbert, W.A. (1961). J. Soc. Dairy Technol. 14, 56.

Cuthbert, W.A., Egdell, J.W. & Thomas, S.B. (1953). J. appl. Bact. 20, 158.

Davis, J.G. (1951). Milk Testing London: Dairy Industries.

Davis, J.G. (1959). Milk Testing 2nd Ed. London: Dairy Industries

Davis, J.G. (1963). The Med. Officer 110, 299.

Dedak, M. (1959). Proc. XV Int. Dairy Cong. 4, 2052.

Domingo, E. (1953). Proc. 37 Ann. Meet. Chem. Spec. Mfrs Assoc. Inc. 167.

Donovan, Kathleen O. (1959). J. appl. Bact. 22, 131.

Downing, D.M. (1954). J. Milk Fd Technol. 16, 254.

Druce, R.G., Bebbington, Nancy, Elson, K., Hercombe, J.M. & Thomas, S.B. (1957). J. appl. Bact. 20, 1.

Dunkley, W.L. & King, R.L. (1959). J. Dairy Sci. 42, 481.

Eagan, H.E. (1954). J. Milk Fd Technol. 17, 340.

Edinburgh and East of Scotland College of Agriculture (undated). Cleaning and chemical sterilisation of farm dairy equipment. Rural Adv. Lflt. 47.

Egdell, J.W. (1959). J. Soc. Dairy Technol. 12, 220.

Egdell, J.W., Lomax, Kathleen, Adams, R.P. & Aitken, Margaret J. (1958). J. appl. Bact. 21, 109.

Egdell, J.W. & Widdas, Dorinne, R. (1962). Proc. XVI Int. Dairy Cong. A, 385.

Egdell, J.W. & Widdas, Dorinne, R. (1964). N.A.A.S. q. Rev. 1, 63.

Eisenreich, L., Becker, F. & Tewes, G. (1955). Milchwissenschaft, 8. (Dairy Sci. Abstr. (1955). 17, 150.)

Electrical Development Association (1956). Farm Electrical Handbook 4 London.

Electrical Development Association (1965). Farm Electrical Handbook 8 London.

Farm and Industrial Equipment Institute (undated) Minimum standards for c.i.p. milking pipeline systems used on dairy farms. Chicago, U.S.A.

Federation of United Kingdom Milk Marketing Boards (1965). Dairy Facts and Figures 1965. Thames Ditton: Federation of United Kingdom Milk Marketing Boards.

Fisker, A.M. (1949). Proc. XII Int. Dairy Cong. 3, 319.

Fleischmann, F.F., White, J.C. & Holland, R.F. (1950). Fd Inds 22, 168

Fleischmann, F.F. & Holland, R.F. (1953). J. Milk Fd Technol. 16, 9.

Fortney, G.G., Baker, M.P. & Bird, E.D. (1955). J. Milk Fd Technol. 18, 150.

Fouts, E.L. & Freeman, T.R. (1947). J. Dairy Sci. 30, 61.

Futschick, J. (1958). Milchw. Ber. Wolfpassing u Rotholz 867. (Dairy Sci. Abstr. (1959). 21, 347).

Fyfe, J. & McFarlane, I.A. (1965). Scott. Agric. 44, 273.

Garvie, E. & Clark, P.M. (1955). J. appl. Bact. 18, 90.

George, G., Elson, K. & Thomas, S.B. (1956). J. appl. Bact. 19, 215.

Gibson, T. (1943). Proc. Soc. agric. Bact. 13.

Gibson, T. & Abd-el-Malek, Y. (1957). Can. J. Microbiol. 3, 203.

Gibson, T., Stirling, A.C., Keddie, R.M. & Rosenberger, R.F. (1958). J. Gen. Microbiol. 19, 112.

Gilcreas, F.W. & O'Brien, J.E. (1941). Am. J. publ. Hlth 31, 143

Griffiths, D.G. & Thomas, S.B. (1959). J. appl. Bact. 22, 46.

Gyllenberg, H.G., Elkund, E., Antila, M. & Vartiovaara, V. (1960). Acta Agric. Scand. X, 1.

Gyllenberg, H.G., Elkund, E., Antila, M. & Vartiovaara, V. (1963) Acta Agric. Scand. XIII, 177.

Hadland, G. (1957). Meieriposten 46, 299. (Dairy Sci. Abstr. (1960). Rev. Art. 22, 56).

Hall, H.S. (1953). J. Instn Brit. Agric. Engrs 9, 11.

Hammer, B.W. & Babel, F.J. (1957). Dairy Bacteriology New York: Wiley and Sons.

Hankinson, H.G., Carver, C.E., Chong, K.D. & Gordon, K.P. (1965). J. Milk Fd. Technol. 28, 377.

Harding, H.G., Trebler, M.A. (1947). Fd Technol., Champaign 1, 478.

Harker, R.P. (1959). J. Text. Inst.. 50, 189.

Harris, J.C. & Satanek, J.J.(1961). J. Am. Oil Chem. Soc. 38, 169, 244

Harrison, J. (1938). Proc. Soc. agric. Bact. 1, 12.

Havighorst, C.R. (1951). Fd Engng 23, 74.

Hays, G.L., Burroughs, J.D. & Johns, D.H. (1958). J. Milk Fd Technol. 21, 68.

Hensley, J.W., Long, A.O. & Willard, J.E. (1949). Ind. Engng Chem. Fundam. 41, 1415.

Hensley, J.W. (1951). J. Am. ceram. Soc. 34, 188.

Holager, E. (1953). Dairy Sci. Abstr. 15, 56.

Holding, A.J. (1954). J. appl. Bact. 17, xvi.

Holding, A.J. (1960). J. appl. Bact. 23, 515.

Holland, R.F., Shaul, J.D., Theokas, D.A. & Windlan, H.M. (1953). Fd Engng 25, 75.

Hoy, W.A. & Clegg, L.F.L. (1953). Proc. Soc. appl. Bact. 16, 1.

Hoy, W.A. & Rowlands, A. (1948). Proc. Soc. appl. Bact. 11, 40.

Hucker, G.J. (1942). N.Y. Agric. Exp. Sta. Geneva, N.Y. 43.

Hucker, G.J., Emery, A.J. & Winkle, E. (1951). J. Milk Fd Technol. 14, 95.

Hughes, A.E. & Ellison, D. (1948). Proc. Soc. appl. Bact. 11, 22.

Hughes, R.C. & Bernstein, R. (1945). Ind. Engng Chem. Fundam. (Ind. Ed. 37, 170.

Hunter, J.E., Marth, E.H. & Frazier, W.C. (1954). J. Milk Fd Technol. 17, 43.

International Association of Milk and Food Environmental Sanitarians (1966). Rep. of Farm Methods Committee. Chicago.

Jackson, H. & Clegg, L.F.L. (1964). J. Dairy Sci. 47, 676.

Jennings, W.G. (1959a). J. Dairy Sci. 42, 476.

Jennings, W.G. (1959b). J. Dairy Sci. 42, 1763.

Jennings, W.G. (1960). Fd Technol., Champaign 14, 591.

Jennings, W.G. (1961). Dairy Sci. Abstr. Rev. Article 96.

Jennings, W.G. (1963). J. Am. Oil Chem. Soc. 40, 17.

Jennings, W.G., McKillop, A.A. & Luick, J.R. (1957). J. Dairy Sci. 40, 1471.

Jensen, J.M. (1946). J. Dairy Sci. 29, 453.

Jensen, J.M. (1951). Proc. Milk Industry Fundation Convention 2, Plant Sec.

Jensen, J.M. & Claybaugh, G.A. (1951). J. Dairy Sci. 34, 865.

Johns, C.K. (1946). Am. J. publ. Hlth 37, 1322.

Johns, C.K. (1960). Can. Dept Agric. Publ. 1084.

Johns, C.K. (1962). Dairy Engng 79, 156.

Johns. C.K. (1962). Proc. XVI Int. Dairy Cong. D, 35.

Johns, C.K. (1967). Personal communication June 14.

Johns, C.K. & McClure, A.D. (1961). J. Milk Fd Technol. 24, 362.

Kaufmann, O.W. & Tracy, P. (1959). J. Dairy Sci. 42, 1883.

Kaufmann, O.W., Hedrick, T.I., Pflug, I.J., Phiel, C.G. & Keppeler, R.A. (1960). J. Dairy Sci. 43, 28.

Kaufmann, O.W., Hedrick, T.I., Pflug, I.J. & Phiel, C.G. (1961). Mich. St. Agric. Sta. Res. Bull. 43, 508.

Kline, C.K. & Fox, R.D. (1966). Agric. Ext. Serv. Michigan Sta. Univ. Inf. Series 168.

Kling, W. & Lange, H. (1960). J. Amer. Oil Chem. Soc. 37, 30.

Kosikowski, F.V. & Holland, R.F. (1955). N.Y. Sta. Coll. Agric. Ext. Bull. 941.

Levandowski, T. (1958). J. Dairy Sci. 41, 249.

Lindamood, J.B., Finnegan, E.J. & Garf, G.C. (1955). J. Dairy Sci. 38, 615.

Lindquist, B. (1953). Proc. XIII Int. Dairy Cong. 3, 877.

Lisboa, N.F. (1959). Proc. XV Int. Dairy Cong. 3, 1816.

Lisboa, N.F. (1967). Personal communication September 8.

Major, W.C.T. (1962). Qd Agric. J. 19, 123.

Mallman, W.L., Zackowski, L & Hahler, D. (1947). Natl Sanitation Found. Ann. Arbour Michigan. Res. Bull. 1.

Mann, E.H. & Ruchhoft, C.C. (1945). Publ. Hlth Rep. 61, 677.

Masurovsky, E.B. & Jordan, W.K. (1958). J. Dairy Sci. 41, 1342.

Masurovsky, E.B. & Jordan, W.K. (1960). J. Dairy Sci. 43, 1545.

Mattick, A.T.R. (1921). J. Hyg. Camb. 20, 165.

Mattick, A.T.R. (1929). J. Dairy Res. 1, 111.

Mattick, A.T.R. & Hoy, W.A. (1937). Bottle washing and bottle washing machines. Reading: National Institute for Research in Dairying.

Maxcy, R.B. (1963). J. Dairy Sci. 46, 611.

Maxcy, R.B. (1964). J. Milk Fd Technol. 27, 135.

Maxcy, R.B. (1966). Fd Technol., Champaign 20,, 123.

Maxcy, R.B. & Shahani, K.M. (1960). J. Dairy Sci. 43, 856.

Maxcy, R.B. & Shahani, K.M. (1961). J. Milk Fd Technol. 24, 122.

McCulloch, S.W. (1963). J. Soc. Dairy Technol. 16, 162.

McCulloch, S.W. (1965). J. Soc. Dairy Technol. 18, 36.

McDowell, F.E. (1942). N.Z. Jl Sci. 23, 146A.

McEwan, C.K. (1967). Personal communication. June 19.

McFetridge, M.J. (1959). N.Z. Jl Agric. April.

McFetridge, M.J. (1962). Proc. XVI Int. Dairy Cong. A, 441.

McGregor, D.R., Elliker, P.R., & Richardson, G.A. (1954). J. Milk Fd Technol. 17, 136.

McKenzie, D.A. & Bowie, D.A. (1949). Proc. Soc. appl. Bact. 9, 35.

McKenzie, A. & Dick, M. (1959). Soap Chem. Spec. 35, 79.

Mead, M. & Pascoe, J.V. (1952). Aust. J. Dairy Technol. 7, 114.

Merrill, E.P., Jensen, J.M. & Bass, S.T. (1962). J. Dairy Sci. 45, 613, 796.

Middleton, Marjorie S., Panes, J.J., Widdas, Dorinne R. & Williams, G. (1965). J. Soc. Dairy Technol. 18, 161.

Ministry of Agriculture, Fisheries & Food (1954). Sterilising farm dairy utensils with approved hypochlorite. Advisory Leaflet 422, London: H.M.S.O.

Ministry of Agriculture, Fisheries & Food (1955a). The use of rinses, swabs and milk samples in farm advisory work N.A.A.S. Tech. Bull. 79. London: H.M.S.O.

Ministry of Agriculture, Fisheries & Food (1955b). Bacteriological examination of farm dairy advisory samples N.A.A.S. Tech. Bull. 79. London: H.M.S.O.

Ministry of Agriculture, Fisheries & Food (1959). Cleaning and chemical sterilisationoof farm dairy utensils Adv. leaflet 422. London: H.M.S.O.

Ministry of Agriculture, Fisheries & Food (1962). Rep. bact. techniques for dairy purposes Sections 2, 3 & 4. London: H.M.S.O.

Ministry of Agriculture, Fisheries & Food (1966). Short term leaflet 26 London: H.M.S.O.

Model Dairy Bye-Laws (1961). Report of the Committee appointed by the Secretary of State for Scotland. Edinburgh: H.M.S.O.

Mohr, W. & Junger, R. (1963). Proc. XIII Int. Dairy Cong. 3, 851.

Moore, D.R., Tracy, P.H. & Ordal, Z.J. (1951). J. Dairy Sci. 34, 804.

Moore, A.V. (1951). Milk Dlr 41, 146.

Morgan, D.M. & Lankler, J.G. (1942). Ind. Anal. Chem. Anal. Ed. 14, 729

Murray, J.G. (1949). Proc. Soc. appl. Bact. 12, 20.

Murray, J.G. & Downey, G. (1962). Rec. agric. Res., Nth Ire. 11, 91.

Murray, J.G., Downey, G. & Foote, A.G. (1962). Rec. agric. Res., Nth Ire. 11. 101.

Murray, J.G. & Foote, A.G. (1963). Rec. agric. Res., Nth Ire. 12, 49.

Nakanashi, T. & Hyogal, Y. (1962). Proc. XVI Int. Dairy Cong. 1, 433.

National Agricultural Advisory Service (1942). Tech. Bull. 75, 79.

National Agricultural Advisory Service (1967a). The user's guide to modern milking 1.

National Agricultural Advisory Service (1967b). The user's guide to modern milking 2.

Neave, F.K. & Hoy, W.A. (1947). J. Dairy Res. 15, 24.

Niven, W.W. (1955). Industrial Detergency New York: Reinhold Pub. Cor

Nokes, E.J. & Tredennick, J.E. (1965). Investigation of circulation cleaning under normal farm conditions Bristol: Minist. Agric. Fish. Food.

Olsen, H.C., Brown, G.O. & Mickle, J.B. (1960). J. Milk Fd Technol. 23, 6.

Orr, Margaret M. (1967). Personal communication Aug. 17.

Parker, R.B., Caldwell, A.C. & Elliker, P.R. (1963). J. Milk Fd Techno 16, 136.

Parker, R.B., Elliker, P.R., Nelson, G.T., Richardson, G.A. & Wilster, G.H. (1953). Fd Engng 25, 82.

Patel, S. & Jordan, W.K. (1964). J. Milk Fd Technol. 27, 66.

Peters, J.J. (1959). Diss. Abstr., Madison Univ. Win. 20, 819.

Peters, J.J. & Calbert, H.E. (1960). J. Dairy Sci. 43, 837.

Petto, J.W. (1962). Proc. XVI Int. Dairy Cong. D, 1, 333.

Pflug, L.I.T., Hedrick, T.I., Kaufmann, O.W., Keppeler, R.A. & Phiel, C.G. (1961). J. Milk Fd Technol. 24, 390.

Phillips, G.M. (1962). Rhodesia agric. J. 59, 303.

Quist, E.A. (1963). J. Milk Fd Technol. 26, 322.

Reynolds, O. (1901). Cambridge Univ. Press 81.

Rhodes, F.H. & Brainard, S.W. (1929). Ind. Engng Chem. 21, 60.

Richard, J. & Auclair, J.E. (1962). Proc. XVI Int. Dairy Cong. 1, 2, 29

Ridenour, G.M. & Armbruster, E.H. (1953). Am. J. publ. Hlth 43, 138.

Robertson, A.H. (1925). N.Y. Sta. agric. Exp. Sta. Tech. Bull. 112.

Rogosa, M., Mitchell, Joyce A. & Wiseman, R.A. (1951). J. Bact. 62, 132

Scheib, B.J. (1966a). Cent. Ontario Milk Sanit. Ass. 8th Ann. Meeting Ontario.

Scheib, B.J. (1966b). Personal communication, June 22.

Scott, W.I.,,Whittlestone, W.G. & Lutz, P. (1962). Aust. J. Dairy Technol. 17, 112.

Scottish Milk Marketing Board (1964). Scottish Farm Census Glasgow: S.M.M.B.

Sieberling, D.A. & Harper, W.V. (1956). J. Dairy Sci. 39, 919.

Sharpe, Elisabeth M. (1960). Lab. Pract. 9, 223.

Sheuring, J.J. & Folds, G.R. (1953). Milk Pl. Mon. 42, 48.

Smith, G.A. (1957). Milk Prod. J. 48, 14.

Smith, R.L. (1959). The Sequestration of Metals. London: Arnold & Co.

Snudden, B.H., Calbert, H.E. & Frazier, W.C. (1961). J. Milk Fd. Technol. 24, 437.

Society of Dairy Technology (1959). In-place cleaning of dairy equipment London: S.D.T.

Somers, Ira I. (1949). Fd Inds 21, 295.

Stephan, H.P. (1955). Dairy Prod. J. 46, 50.

Swartling, P.A. (1959). Dairy Sci. Abstr. 21, 1.

Swift, S., Alexander, W. & Scarlett, C.A. (1963). Circulation cleaning investigation. Ministry of Agriculture, Fisheries and Food (South Eastern Region).

Thiel, C.C. (1959). Dairy Fmr, Ipswich 6, 45.

Thiel, C.C. (1962). J. Soc. Dairy Technol. 15, 94.

Thiel, C.C., Clegg, L.F.L., Clough, P & Cousins, Christina M. (1956). J. Dairy Res. 23, 217.

Thom, V.M. (1962). Proc. XVI Int. Dairy Cong. A, (2), 409.

Thomas, S.B. (1963a). J. Soc. Dairy Technol. 16, 126.

Thomas, S.B. (1963b). Dairy Inds 28, 37.

Thomas, S.B. (1964). J. Soc. Dairy Technol. 17, 37.

Thomas, S.B., Druce, R.G. & Davies, Angela, (1966). Dairy Inds 31, 27.

Thomas, S.B., Druce, R.G., Hobson, Phyllis M. & Makinson, P.E. (1964). Unpublished data (Thomas, Druce & King, 1964).

Thomas, S.B., Druce, R.G., Hobson, Phyllis M. & Williams, G. (1963). Dairy Inds 28, 390.

Thomas, S.B., Druce, R.G. & King, Kay P. (1964). J. appl. Bact. 27, 7.

Thomas, S.B., Druce, R.G. & King, Kay P. (1966). J. appl. Bact. 29, 40

Thomas, S.B., Egdell, J.W., Clegg, L.F.L. & Cuthbert, W.A. (1950). Proc. Soc. appl. Bact. 13, 27.

Thomas, S.B., Ellison, Dorothy, Griffiths, D.G., Jenkins, E. & Morgan K.J. (1950). J. Soc. Dairy Technol. 3, 187.

Thomas, S.B., Evans, E. Jones, Jones, L.B. & Thomas, Blodwen F. (1946). J. appl. Bact. 9, 51.

Thomas, S.B., Griffiths, D.G., Davies, Elsie & Bebbington, Nancy B. (19 Dairy Inds 17, 791.

Thomas, S.B., Griffiths, Janet R. & Foulkes, J.B. (1962). Dairy Inds 17, 243.

Thomas, S.B., Griffiths, Janet R. & Foulkes, J.B. (1963). Dairy Engng 78, 251.

Thomas, S.B., Hobson, Phyllis M. & Elson, K. (1958). J. appl. Bact. 21, 58.

Thomas, S.B., Hobson, Phyllis M.& Elson K. (1964). J. appl. Bact. 27, 15.

Thomas, S.B., Hobson, Phyllis M. & Griffiths, D.G. (1954). J. Soc. Dairy Technol. 7, 108.

Thomas, S.B., Hobson, Phyllis M. & Bird, Elizabeth R. (1959). Proc. XV Int. Dairy Cong. 3, 1334.

Thomas, S.B., Hobson, Phyllis M., Bird, Elizabeth R., King, Kay P., Druce, R.G. & Cox, D.R. (1962). J. appl. Bact. 25, 107.

Thomas, S.B., Hobson, Phyllis M., King, Kay P. & Griffiths, Janet M. (1963). Dairy Engng 80, 290.

Thomas, S.B. & Jones-Evans, Eleanor (1947). Dairy Inds 12, 347.

Thomas, S.B., Jones, Mena, Hobson, Phyllis M., Williams, G. & Druce R.G. (1963). Dairy Inds 28, 212.

Thomas, S.B., Thomas, Blodwen, R. & Ellison, Dorothy, (1953). J. Soc. Dairy Technol. 6, 138.

Thornborrow, B. (1960).. Fmrs' Wkly 52, (12), 119.

Tjotta, A. & Solberg, P. (1955). Tidsskr. norske Landbr. 62, 132. (Dairy Sci. Abstr. (1956). 18, 741.)

Topley, W.W.C. & Wilson, G.S. (1955). Principles of Bacteriology and Immunity 4th Ed. London: Arnold.

Turner, C.N. (1964). N.Y. Sta. Coll. Agric. Cornell Ext.Bull. 1137.

University of California (1964). Milking management Pub. AXT 94.

Utermohlen, W.R. Jr., & Wallace, D.L. (1947). Textile Res. 17, 67.

Utermohlen, W.R. Dr. & Wallace, D.L. (1949). Ind. Engng Chem. Fundam. 41, 2861.

Vaughn, T.H., Vittone, A., Jr. & Bacon, L.R. (1941). Ind. Engng Chem. Fundam. 33, 1011.

Walter, W.G. (1948). Am. J. publ. Hlth 38, 246.

Walters, A.H. (1964). Dairy Engng 81, 10.

Walters, A.H., Cousins, Christina M. & Edmunds, S.B. (1949). J. Soc. Dairy Technol. 2, 136.

West of Scotland Agricultural College (1966). Ann. Rep. Dairy Technol. Dept

West of Scotland Agricultural College (1964). Hygienic methods of milk production Adv. leaflet 82.

White, J.C. (1962). Am. Milk Rev. 24, 32.

Whiting, W.A. (1924). N.Y. Sta. agric. Exp. Sta. Tech. Bull. 98.

Whittlestone, W.G. & Phillips, D.S.M. (1955). J. Soc. Dairy Technol. 8, 156.

Whittlestone, W.G. & Lutz, P. (1962). Aust. J. Dairy Technol. 17, 101.

Whittlestone, W.G., Fell, L., Calder, B.D.E. & Galvin, R.H. (1963). Aust. J. Dairy Technol. 18, 179.

Whittlestone, W.G., Beckley, N.S. & Cannon, H.W. (1964). J. Dairy Sci. 47, 713.

Widdas, Dorinne, R. (1961). Fmrs' Wkly 54, (18), 91.

Window, J.G. (1953). Dairyman 70, 421.

Wutzel, S.A. (1953). Agric. Engng St. Joseph, Mich. 34, 157.

Wright, N.C. (1936). Biochm. J. 30, 1661.