

Part I

**DEFINITION AND BACKGROUND OF
MODERN PASTEURIZATION**

CHAPTER 1

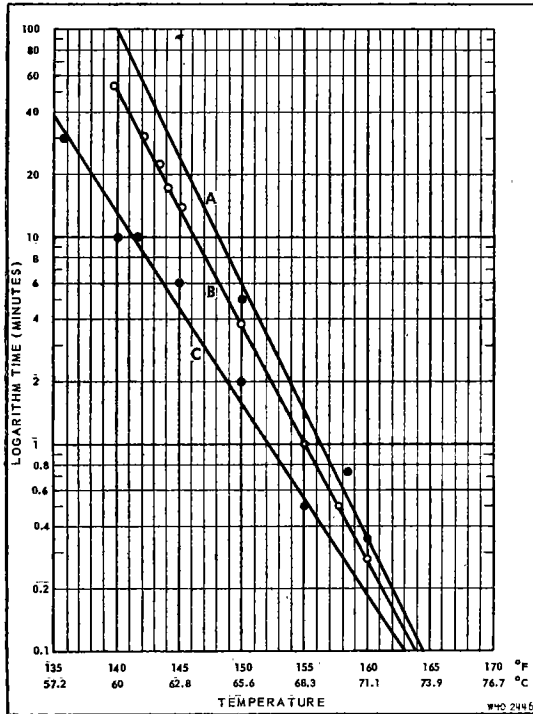
DEFINITION OF MODERN PASTEURIZATION

The pasteurization of milk may be briefly defined as heating milk to a temperature below the boiling-point for a period of time sufficient to kill (*a*) all the common types of pathogenic organisms which may be present in milk, so as to render it safe for human consumption, and (*b*) such a proportion of those adventitious non-pathogenic organisms which may cause spoilage of various types, as to ensure that the milk will keep under all reasonable temperature conditions sufficiently long to enable it to be transported, distributed, and consumed as liquid milk, or utilized for further processing or manufacture.

The exact interpretation of the word pasteurization in terms of time and temperature of heating varies considerably from country to country. It would, however, seem to be reasonable to insist that the temperature of heating shall be no higher and the time no longer than is essential to ensure both freedom from pathogenic organisms and a satisfactory keeping quality for the milk. These essentials, with the margins of safety necessary in practice, appear to have been achieved in the processes in common use in Great Britain and the USA and in many other countries of the world. The time-temperature combinations which have given excellent results in these countries are heating at 61°C to 63°C, or slightly higher (but not exceeding 65.5°C), for not less than 30 minutes, or at 71°C to 72°C for not less than 15 seconds, followed immediately by adequate cooling, usually to not more than 10°C.

The first of these processes, known as the "holder" process, has been in general use for many years and has stood the test of time. The second, or "high temperature short time" (usually called "HTST" or occasionally "high short", or in Scandinavian countries "low pasteurization") process, has also been successfully used for several years. Theoretically, there is an almost infinite number of combinations of time and temperature which would have much the same effect upon the milk and the organisms in it. But in practice, if temperatures much below 61°C or much above 72°C are used, difficulties are encountered: in the first case, the desired destruction of organisms may either not be achieved or be achieved only after prolonged heating; in the second case, overheating, leading to cooked flavours and loss of "cream line", is difficult to avoid. To ensure that it will keep *indefinitely*, commercial milk must be sterilized under

FIG. 1. DAHLBERG'S SCALE OF TIME-TEMPERATURE VALUES FOR MILK PASTEURIZATION



- A = cream layers reduced
 B = standard for pasteurization
 C = thermal death-points

From Dahlberg, ⁴ by kind permission of the New York State Agricultural Experiment Station

pressure at temperatures well above 100°C. Such milk, if only because of physical changes, has in many countries only a limited acceptability, but is, of course, valuable under special conditions.

When pasteurization by the holder or the HTST process is carried out scrupulously at all its stages, and after-contamination avoided, the safety of the milk is assured and its keeping quality is adequate for all ordinary purposes. Heat in all forms is now expensive and, unless actual sterility is aimed at, there appears to be no advantage in heating milk to temperatures greatly above 72°C. Above this temperature, milk soon begins to lose its "cream line". This is seriously impaired if milk is held for 15 seconds at even a degree or so above 72°C and is rapidly lost at temperatures above 74°C.

A useful indication of the range of possible time-temperature combinations is illustrated in fig. 1, based on the work of Dahlberg.⁴ (See also Dahlberg⁵ and Holland & Dahlberg.¹⁶) It will be seen that he has selected a number of time-temperature combinations as standards for pasteurization, after allowing a reasonable margin of safety over and above those at which all harmful bacteria are destroyed.

The scale of values marked A on fig. 1 shows the time-temperature combinations at which cream layers are reduced, or at which "cream line" is impaired. "Cream line" is a commercial factor of importance in some countries where the consumers like to see a deep band of "cream" on the top of their bottle of milk, but in those parts of the world where there is no such established tradition, it is not likely to play any great part. It will be seen, however, that all the time-temperature combinations shown in fig. 1 fall below that at which cream layers are reduced.

There is, of course, no very serious reason, if local experience shows that the consumer is not averse to cooked flavours nor worried about the apparent absence of cream from his milk, why the temperature of the holder or of the HTST process should not exceed by a degree or two the maxima mentioned earlier in this chapter.

It is claimed by some that this procedure, particularly under tropical conditions, gives an additional margin of safety and of keeping quality with no serious loss in flavour or other consumer-value. Buffalo milk, it is also stated, will keep its cream line at temperatures well above the quoted maxima.

If there is any doubt about the adequacy of the pasteurization technique, or any proved local advantage to be gained, it is obviously better to err on the side of the higher ("full heat-treatment") than the lower pasteurization temperatures. In this (as in most matters of technical detail), the working conditions in different countries must ultimately be decided from well-considered local experience and embodied in local legislation.

BACKGROUND OF MODERN PASTEURIZATION

Pasteurization and Health

During the last 50 years, the populations of the towns in most parts of the world have become much greater, while the milk-producing areas have tended to recede more and more from the main centres of population. This has led in practice to a greater degree of bulking of milk at the source of supply, the indifferent milk often being mixed with the good. It can be said with truth that all large bulks of raw milk are potentially dangerous to the human or even the animal consumer. They are liable at all times to contain pathogenic organisms. In 1934, Pullinger²³ showed that 100% of raw-milk samples from large—13,600-litre (3,000-gallon)—road- or rail-tankers contained living tubercle bacilli. It is also true that, in recent years, the size of pasteurizing plants in terms of daily output has gradually increased and, as a consequence, more people are drinking milk which has been pasteurized in the same plant. This too has important public-health implications, because it means that any fault in the processing of the milk, or any defect in the machinery which carries it out, can have, in present-day conditions, far more serious consequences than would have been the case, for example, 25 years ago. In the face of the changed social needs and habits of the people of the world, and in particular those of urbanized areas, there is now no doubt whatever that the efficient heat-treatment of milk is a prime social necessity and that, without it, the maintenance of adequate standards of public health would be seriously hampered.

While the presence of living tubercle bacilli in milk is one of the most serious dangers to the health of those consuming raw, or improperly pasteurized, milk, the seriousness of infection from this organism has tended to obscure the fact that other pathogenic bacteria are not infrequently present.

Thus, *Brucella abortus*, which causes abortion in cows and undulant fever in man, is commonly present in raw milk because it localizes in the udder of a proportion of cows suffering from the disease, and gains access to the milk with the discharges. Some cases of infection of the udders of cows with the related *Br. melitensis*, the cause of Malta fever in man, have also been reported. Recently, in America, Australia, and England, the presence in milk of *Rickettsia burneti*, the cause of Q fever in man, has

been demonstrated. It has also been shown that, when present in the numbers likely to be found in milk, this organism is destroyed by pasteurization. The extent of *R. burneti* infections in most other parts of the world is not yet known. These are examples of animal infections transmissible to man and occurring from time to time in bulk raw-milk supplies.

The epidemic diseases are more spectacular because they cause rapid and widespread infection in man, usually with a proportion of deaths. Among these is septic sore-throat, which is caused by streptococci and is ultimately human in origin, but also infects some cows. The large milk-borne outbreak in Brighton, England, in 1929, involved 1,000 families and caused 65 deaths.²⁷ Diphtheria, scarlet fever, and the enteric infections may also be carried by raw milk; in the case of enteric infections, the milk may be contaminated through infected water-supplies on farms as well as directly from human sources. All the organisms causing these diseases are killed by pasteurization.

This means that infections or epidemics which may be milk-borne can be prevented in areas where raw milk is adequately heat-treated before sale. The striking effect of the introduction of pasteurization of milk on infection of the human consumer is illustrated by the virtual elimination of tuberculosis of bovine origin in the populations of those large cities, of Europe, of the USA, and of other parts of the world, where pasteurized milk has almost completely replaced raw milk. A detailed discussion of the effect of pasteurization on the extent of milk-borne disease in various countries where records exist cannot be attempted here, but an objective account of the available experience up to 1939 is given by Wilson.²⁸ All information since that date has amply confirmed that pasteurization, properly carried out, can virtually abolish the danger of infectious or epidemic diseases whose causative organisms are conveyed by raw milk. Nevertheless, it is essential at all times, and by far the most important reason for an adequate system of control of the quality of commercial pasteurized milk as it reaches the consumer, to make quite sure that pasteurization has been effectively carried out and that post-pasteurization re-contamination has been avoided. The typhoid epidemics in 1927 in Montreal, Canada,²⁸ and in 1935 in Rome, Italy,^{19, 24} the scarlet-fever outbreak in 1931 in Glasgow, Scotland,²⁸ and other outbreaks of disease arising from so-called "pasteurized" milk provide convincing evidence of the dangers which may arise when milk from a pasteurizing plant is inadequately heated, contaminated by raw milk, or—as in the Rome epidemic—put into bottles which had been washed in polluted water. Mere perfunctory use of the most up-to-date modern plant must not be allowed to give rise to complacency.

The modern pasteurizing plant, with its automatic controls and registering devices, is undoubtedly an example of precision engineering, but the

safety and success of its working still depend both on the proper training of operators and on adequate laboratory control of the pasteurized product by a staff with specialized techniques, proper facilities, and unhindered access to the plant at every stage of the process. Without properly trained operators and regular testing of the milk (see Part III, "Laboratory control") by competent laboratory personnel, even the best of plants may at times, and a poorly-designed plant certainly will, cease to be a safeguard. It is quite essential that those officially responsible for licensing pasteurization plants should themselves be familiar with their construction and performance, so that none but satisfactory plants are permitted. They should, moreover, bear in mind that even a simple plant of sound design can, if skilfully and conscientiously operated and adequately controlled, give consistently satisfactory results.

After milk has been pasteurized, it should be distributed in bacteriologically clean bottles, or other final containers rendered safe by proper sterilization, and adequately sealed. If pasteurized milk is distributed in bulk it loses something of its guarantee of safety because adventitious contamination may take place at any time.

While there can be no doubt that the pasteurization or other equally effective heat-treatment of milk is an essential public-health measure, to be carried out faithfully at all seasons of the year, its commercial value is not to be disputed. Without pasteurization it would be difficult, though not, as Swiss experience has shown, completely impossible, to provide large urban populations with sweet milk at an economic price. The destruction of those organisms in raw milk which cause souring or other faults renews its "life", which may be considered to begin from the time of pasteurization.

There is also good reason for recommending the heat-treatment of surplus milk, skim milk, buttermilk, whey, and other by-products fed to animals, because they also are susceptible to milk-borne diseases. Pigs, calves, and other farm animals may be readily infected with tuberculosis if fed with skim milk, whey, etc., returned without heat-treatment from a milk factory where the milk has been bulked. In practice, this heat-treatment can, if no better method is available, be effected simply by blowing clean steam into the skim milk, etc., until the temperature reaches 67°C. The 10% (approximately) dilution with condensed steam is not of serious consequence if the by-products are to be fed to animals.

While effective pasteurization makes milk—even milk which may have originally contained pathogenic organisms—safe to drink, it is to be stressed that it does *not* make any less compelling the necessity of eradicating disease from dairy herds. Disease in his herd handicaps the dairy farmer at every turn. Apart from the danger caused to human personnel, it wastes his time, his materials, his feeding-stuffs, his animals, and his money; it

ruins his breeding programme and, if not checked, may eventually bring him to ruin also.

Effect of Pasteurization on Nutritive Value of Milk

Vast human experience and incontrovertible experimental findings agree as to the great value of the milk of different mammalian species, and particularly of the value of cow's milk, as a foodstuff for man. This value is proportionately greater the poorer the original basic diet; for example, children living almost exclusively on cereals give a greater percentage response to a given addition of milk than children living on a good mixed diet.

In many countries a large proportion of the juvenile population depends on cow's milk as its main source of calcium, of high-quality protein, of vitamin A, and of some of the B vitamins. Though this dependence diminishes somewhat with increasing age, the fact remains that milk is an excellent foodstuff for man at all stages of his life-history.

It was suggested some 30 years ago, when pasteurization was becoming more general in many of the more-advanced countries, that this process robbed milk of important nutritional qualities. If this were the case, the awkward question would have to be decided as to whether the undoubted advantages of pasteurization in destroying the potential disease-producing micro-organisms in milk, and in permitting milk to be handled in bulk and distributed without souring to urban populations, outweighed the nutritional disadvantages of heat-treatment.

Fortunately, the original suggestion that pasteurization seriously diminished the nutritive value of milk has been proved conclusively to be ill-founded. In a lengthy series of carefully controlled experiments,²⁰ it has been demonstrated beyond doubt that the effects of pasteurization, properly conducted, on the nutritive value of milk are very small. Much of the experimental work has been done with holder-pasteurized milk. In such milk, the availability of the milk protein, the calcium, the phosphorus, the vitamins A and D, and most of the B vitamins—e.g., pyridoxine, nicotinic acid, pantothenic acid, biotin—is unaffected. There are losses of 10%-25% in aneurin (thiamine), a loss of about 20% in vitamin C (not entirely due to the pasteurization process itself, but largely a result of the destructive effect of daylight on this vitamin), and still smaller losses in riboflavine (again largely due to the effect of light). The nutritive losses induced by the HTST process are even smaller, aneurin and vitamin C being virtually unaffected by this process.

The only effect of the holder process which can be regarded as other than negligible is the loss of up to 20% of the original vitamin-C content

of the fresh raw milk. Milk, whether raw or pasteurized, is a poor source of vitamin C, and it is considered good paediatric practice, where infants are living entirely or almost entirely either on mother's or on cow's milk, to add fruit juice, vegetable juice, or a purée of fruit or vegetable containing this vitamin, to their diet.

To sum up, the effect of the process of HTST pasteurization, properly conducted, on the nutritional value of milk is quite negligible; the effect of the holder process is negligible apart from the small loss of vitamin C. In fact, the effects of seasonal conditions or farm management on the composition of milk, such as, for example, the depressant effect on vitamin-A content of the winter feed of the cows in some northern countries, are much more important to the consumer than any type of heat-treatment.

Effect of Pasteurization on Flavour of Milk

Statements have been made from time to time as to the effect of pasteurization on the flavour of milk; some have been in favour of pasteurized milk, others in favour of raw milk. Experimentally, there seem to be very few persons indeed who can detect by sensory means the difference between raw and pasteurized milk. A careful trial carried out some years ago²⁸ may be reported briefly in the investigator's own words:

“In an experiment in which nine different observers tasted 14 raw and 16 pasteurized milks distributed at random the number of mistakes made was almost the same as would have been expected by chance alone on the assumption that there is no characteristic difference between them.

“Only one observer, a schoolgirl aged 11, succeeded more often than would have been expected by chance alone in correctly identifying the nature of the milks; and even she made 8 mistakes out of 30. None of the other observers was able to approach this record” (page 103).

It can safely be concluded from these experiments and from general experience that pasteurization, when properly carried out, has very little effect on the flavour of milk. This applies equally to the holder and the HTST pasteurization processes.

Raw Milk in Relation to Pasteurization

In any well-developed modern community, it should be regarded as a necessity that every milk producer who wishes to sell his milk off the farm, for whatever purpose the milk is to be used afterwards, and irrespective of whether or not it is to be pasteurized, should produce and handle that milk on the farm in a clean and responsible way. It should, for example, come from cattle which, as far as can be humanly determined, are free

from any disease which might infect, or otherwise deleteriously affect, the milk. It should be as free as possible from dirt or adventitious contamination with micro-organisms ; it should be kept clean and cool until it leaves the control of the producer ; it should be of satisfactory compositional quality.

The detailed consideration of farm methods, such as, for example, selection of dairy cattle, precautions in relation to animal health, and the technique of the use of the milking machine, do not come within the scope of this monograph, but a few general principles regarding milk production require mention since they have a bearing on pasteurization. If these principles are not applied on the farm, the milk produced, especially during the warmer seasons of the year, may be quite unfit for processing.

It cannot be denied that many of the problems of the commercial utilization of milk, whether it is to be used for pasteurization or for the manufacture of dairy products, arise on the farm. They arise there through lack of knowledge, lack of facilities, or carelessness.

Knowledge

As regards knowledge, successful modern milk-production requires technical skill and, therefore, adequate training of the farm staff concerned. The notion is sometimes met with that the practical care of dairy animals and milking methods are so simple that special instruction is unnecessary. In fact, modern dairy-farm technique, both inside and outside the milking shed, is highly skilled, and a sound basis of practical instruction and a high standard of performance are required if the milk produced is to be of marketable quality at all seasons of the year.

Most well-developed countries have organizations for the instruction of the young farmer or farm worker in many aspects of practical farming, including modern dairy-farm technique. All that need be said on this question in the present monograph is that if milk previously used locally in such countries for cheese- or butter-making is to be transported to collecting centres for pasteurization or other form of bulk processing, the methods in use in the milking shed will in most cases have to be tightened up, and additional technical instruction for farm workers may be necessary. In such countries, it should not be too difficult to provide, after a fairly short period of readjustment, a raw milk of the requisite standard for any type of subsequent processing.

On the other hand, in some less-well-developed countries, where training organizations do not exist and yet where the decision has been made to engage seriously in the production of raw milk of the right hygienic quality for bulk processing, it cannot be too strongly emphasized that an essential pre-requirement, if serious difficulties are to be avoided, is the dissemina-

tion to milk producers of the requisite "know-how". This may entail the training of potential instructors in foreign countries and the subsequent establishment of special courses of instruction, which need not be too elaborate, in the home country. It will certainly entail patience on the part of the administrators and others concerned.

Experience has shown that, in such countries, the most satisfactory path of progress is the employment, for a period, of sagacious personnel from outside, personnel with sound and wide understanding of the underlying principles of producing and processing milk. The advantage to local administrators of the advice and assistance of such experienced men is obvious. The policy of sending students overseas to learn modern techniques, to be applied in their own countries on their return, is more likely to be successful when a really wise and resourceful hand can guide them in steadily adapting the principles—but not necessarily every detail—of what they have learnt in a foreign country (a country with, perhaps, rather widely different conditions of milk production) to the development of a milk industry in their own country. Thus, regulations to be observed on the milk-producing farm need not, at the beginning, be other than simple, even if they fall short of the ideal ultimately to be aimed at, but they must, nevertheless, be founded on sound principles.

Facilities

As regards facilities on the dairy farm, the main requirements are :

- (1) light, so that the cowman can see what he is doing at any time of the day or night ;
- (2) water and soap (or other detergent), so that hands, udders, teats, and equipment may be properly cleansed ;
- (3) steam or very hot water, or—a rather poorer alternative—disinfectant, so that everything that comes in contact with milk may be sterilized (steam in some form of sterilization chest is preferable).

A high proportion of the bacteria in freshly produced raw and pasteurized milk is derived from the surfaces of milk-handling equipment. To prevent or minimize contamination from these surfaces requires their thorough washing and sterilization. Washing and sterilization are two separate processes ; the former involves the removal of dirt and all traces of milk residue and the latter the destruction of bacteria remaining on the surfaces after washing. Failure to wash the equipment thoroughly will lead to the accumulation of milk residues which not only form an ideal breeding-ground for bacteria, but also increase the difficulty of sterilization.

The first stage in the washing process is a rinse with clean water (not above 45°C) to remove as much as possible of the milk residues. Subsequent treatment with warm or hot detergent solution is necessary to

remove all traces of milk residues, followed by a final rinse in clean water to prepare the equipment for its final sterilization. Milk equipment may be sterilized with live steam at 90°C to 100°C for 5-10 minutes, by immersion in water at 85°C to 100°C (though this is not particularly convenient), or by chemicals.

Live steam is convenient and highly effective for the sterilization of those items of equipment which either with or without dismantling can be placed in a closed cabinet for treatment. Where steam is not available, good results may be obtained by using water heated to not less than 85°C. The utensils must be totally immersed and should be kept at, or above, this temperature for not less than 15 minutes.

For chemical sterilization, treatment of clean surfaces with hypochlorites of the right strength in "available chlorine" has been found effective and is in widespread use. Where such chlorine solutions are used for sterilization, it is all-important that the surfaces to be treated should be thoroughly washed. More often than not, failure when using chemical sterilization is due to inefficient preliminary washing which makes it difficult, if not impossible, to ensure that the solution covers every part of the surface. Mixing the chlorine solution with a detergent solution aids the wetting of surfaces which is so essential if every organism remaining on the surface is to be subjected to the action of the chlorine.

For the sterilization of milk utensils on the farm, quaternary ammonium compounds are not as reliable as was at one time hoped. It may well be that new compounds or improved methods of application may be developed, but until the reliability of these compounds in practice can be established with greater certainty, their use on the dairy farm cannot be recommended.

It need hardly be added that facilities for washing and sterilization are needed on the farm, whether or not a milking machine is to be used. Serious disappointment may await the milk producer who installs such a machine without a full knowledge of how to use and clean it. Where there are adequate knowledge and cow-shed facilities, and particularly where labour costs are high, the milking machine is an important asset to any dairy farm.

Care

As regards care, the sense of technical responsibility in the farmer and in the farm operative concerned is undoubtedly the most important factor in the regular production, day in and day out, of milk of a quality high enough for modern large-scale handling and processing. Without this sense, training, knowledge, and facilities can count for little; with it, successful milk-production can take place even with relatively poor

facilities. The handicap of inadequate facilities, however, can be overcome only at an exaggerated cost in time and trouble.

With skill, care, and ordinary facilities on the farm, the extent of contamination of milk with micro-organisms can be kept low. But it is commercially impossible to keep *all* the bacteria out, despite the utmost care with the cleansing and sterilization of milk equipment. It is, therefore, necessary, particularly during the warmer months of the year, not only to cool milk on the farm, but also to keep it cool. In this way, the deleterious bacteria, which increase in numbers very rapidly above 18°C, less quickly between 18°C and 15°-16°C, and only slowly below 12°C, remain quiescent until they are destroyed in the pasteurization process.

Cooling to 12°C or below normally requires either a properly designed milk cooler, together with an adequate supply of water of which the temperature even in summer remains below about 10°C, or, alternatively, refrigeration apparatus of which several different types with different capacities and different power sources are now available for farm use.

To those faced with the problem of collecting milk under tropical or subtropical conditions from a multitude of very small peasant producers untrained in milk hygiene—not farmers in the Western sense of the word but small cultivators keeping one or two village cows, often under highly insanitary conditions, with inadequate and certainly unpiped water-supplies, little fuel, and no electric service—some of the foregoing must seem unrealistic. But even these handicaps are being overcome by various local devices, such as milking before sunrise and rapid collection before the sun becomes hot, the use of wet gunny covers on the cans of milk during transport to the pasteurization centre, and other ad hoc expedients that cannot be detailed here.

Transport and Containers

Local circumstances will obviously decide whether transport of milk from the farm to the collecting depot or the pasteurization plant is done by the producer himself or by a vehicle from the collecting centre. In the latter case, the collecting vehicle may or may not call at the farm itself. It is frequently far more convenient for the relatively heavy vehicle, without leaving a made road, to pick up the cans containing the raw milk from a roadside stand to which they have been brought from the farm by the producer. The construction of a simple roadside stand sheltered from the direct rays of the sun is not a difficult matter, and is of great advantage to both parties. If the milk is in a 40-litre to 50-litre (9-gallon to 11-gallon) can or “churn” and is well cooled before being placed on the sheltered

stand, its temperature will rise only very slowly even with a fairly high ambient temperature. Naturally, the milk should not remain on the stand very long before being picked up by the collecting vehicle.

If an all-the-year-round supply of milk is to be provided for an urban area from a dairy-farming district some distance away, transport questions—including the quality of the roads and the extent to which they can be used during adverse weather conditions, the type of vehicle available, possible transport by rail-tanker or by refrigerated van, etc.—loom large. These questions, which receive further attention in chapter 8 (pages 152-157), have naturally to be considered carefully in any country contemplating for the first time the continuous supply of pasteurized liquid milk to an urban population.

It may be added that where transport from farm to depot or collecting centre is by can or "churn", the utmost care must be taken to ensure a clean can both by the collecting centre (steam-sterilizing the empty can before returning it, with sterile lid in position, to the farmer) and by the farmer (checking by inspection the cleanliness and dryness of the can before use and, if necessary, re-sterilizing it on the farm). One of the most effective ways of ensuring poor-quality milk at the collecting centre is for the producer to put his raw milk into a can contaminated with milk residues.

Methods for the control of the quality and the suitability for pasteurization of milk arriving at a collecting depot or processing plant are described in some detail in Part III, "Laboratory control".

Modern milk-production is no haphazard business, but requires a combination of knowledge, up-to-date facilities, and careful craftsmanship, if the product is to provide, during every month of the year, a satisfactory raw material for pasteurization or, in fact, for any type of processing.
