# MILK PASTEURISATION AS A TECHNICAL PROBLEM.

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One of the difficulties in the way of recommending pasteurisation as a general measure for the protection of the milk supply is the fact that as a technical process it is not completely satisfactory, or perhaps better stated, that there are many loopholes for faulty practice. The problems of pasteurisation are not solved merely by enunciating that scientific investigations under laboratory conditions show that certain time-temperature factors are capable and requisite to kill all pathogenic bacteria in milk and that in the process the damage to the milk is neither material nor detrimental. The application of these time-temperature factors under working conditions involves consideration of a number of practical problems. If we are to adopt pasteurisation as a regular part of Public Health practice it is essential to consider these problems and to make the procedure as technically perfect and satisfactory as possible. Any trade objections have to be considered and weighed and, if they are of substance, removed, if that can be done without harm to essential requirements. This is important, since demands which cut across trade needs are likely to be evaded or at least carried out in a lukewarm fashion.

## The type of pasteurisation to adopt.

It is now generally agreed that "Flash" pasteurisation, *i.e.* a process whereby the milk is very rapidly heated to a relatively high temperature for a very short time, is uncertain and unreliable and cannot be accepted as satisfactory. While under laboratory conditions it can give the required results, the factors making for unreliability are too numerous and too difficult to control to make it dependable. Expert opinion is nearly unanimous that low temperature pasteurisation, combined with holding the milk for a definite time at a prescribed temperature, is the most reliable and satisfactory method. This we define as the "holder" type of pasteurisation.

The English standard definition of pasteurisation is that the milk shall be "retained at a temperature of not less than 145° and not more than 150° Fahrenheit for at least half an hour and to be immediately cooled to a temperature of not more than 55° Fahrenheit." Such a precise definition has the great advantage that much scientific work has been done at this time-temperature range and this shows that it is efficient to destroy pathogenic bacteria.

While accepting this method of pasteurisation as the best known at the present time, there are certain defects inherent to this method which are

difficult to overcome. The point is emphasised because it is important not to take the view that the kind of pasteurisation has been settled for all time and that the last word has been said. I believe that something equally reliable and yet more "fool proof" may be evolved. At the present time there are certain other pasteurisation procedures which merit consideration, *i.e.* the three following methods.

*Pasteurisation in the bottle.*

Theoretically this is the most logical method as it precludes subsequent contamination, but the technical difficulties make its extensive use unlikely. The most serious difficulty is to devise a suitable method of heating the bottled milk. Total submergence of the bottle in the hot water is likely to damage the seal and admit water, less than that involves the risk that part of the milk will be maintained at a temperature below what is necessary.

*Electrical treatment methods.*

A good deal of work has been done upon the effect of electrical currents upon milk and as regards their efficiency to kill pathogenic bacteria. There is not unanimity of opinion as to whether the lethal power is due to the heat generated or to electrical action. While the method has been tried on a practical scale its utility has not been established as a commercial method. At present it is merely a procedure with possibilities.

*Stassanisation of milk.*

The plant worked out by Stassano is really a variant of flash pasteurisation, but under conditions which are said to remove the objections to that process. The treatment is in a completely closed pipe system, the milk being forced by a compression pump through tubes in a thin layer 1·25 mm. wide. The apparatus is a twin tube system in three parts, *i.e.* a regenerating section of eight tubes each 3·5 metres long, a heating section of eight tubes each 2·5 metres long and a cooling section of eight tubes each 3·5 metres long. The heat treatment is given as 75° C. for $\frac{1}{4}$ min. with cooling to 11–12° C., or lower if required. This heat treatment is probably adequate to destroy tubercle bacilli according to North and Park (1927) as they give 160° F. for 20 sec. as satisfactory and 75° C. is 167° F.

Hansen (1931) records a few experiments which show the destruction of tubercle bacilli, *Bacillus abortus*, etc. The apparatus is said to be easily cleaned and Hansen remarks "the coating of the tubes has been comparatively slight and by proper flushing with cold water followed by a soda solution the coating has been easily removed on dismantling the tubes."

The efficiency of any apparatus depends not so much on tests carried out under laboratory conditions, but whether in practical working it complies with essential requirements, *i.e.* in this instance that every particle of milk will be raised to 75° C. and kept at that temperature for 25 sec. throughout the working life of the apparatus. One of these pasteurisers has been taken

to pieces for my benefit by the makers in Denmark and it is well devised and constructed. Many more experiments are necessary before one could be satisfied that the above conditions were fulfilled and that, for example, deposits of coagulated albumin did not form to reduce the effective temperature. It is mentioned here as an interesting type of apparatus with definite merits and as an illustration that further studies are being made from which in time the perfect pasteuriser may evolve.

For the present the ordinary "holder" system holds the field and discussion upon pasteurisation plants will be confined to that type.

### Problems of the "holder" type of pasteuriser.

The most important is the time-temperature factor. English experts have adopted a temperature of 145–150° F. for 30 min. As mentioned already, its efficacy can be accepted. At the same time we must also agree that the lower the temperature and the shorter the time which gives efficient results, the better and the less the liability of damage to the milk. In this connection it cannot be ignored that the U.S.A. with its much greater experience of pasteurisation has deliberately adopted a lower heat point than the official English temperature. The United States Public Health Service, Milk Ordinance, 1932, defines this part of pasteurisation as "the process of heating every particle of milk, or milk products, to a temperature of not less than 142° F. and holding at such temperature for not less than 30 minutes." Extensive American experience and investigation suggest that this is adequate.

Outside bactericidal efficiency the two points involved are: first, if any differences can be shown as regards alterations in chemical composition favourable to the lower temperature, and second, whether there are any advantages to the milk trade in the lower temperature.

As regards the first point I am unaware of any comparative studies and probably the matter is of little significance. The second merits more consideration for undoubtedly to the trade there is a critical difference between the two temperatures. This turns upon the question of "the cream line."

The investigations made (*see* Whittaker, Archibald, Shere and Clement, 1925, and Dahlberg and Marqwardt, 1929) show that the temperature of standard pasteurisation enforced in England is liable to affect the cream line. The critical temperature is 145° F. Heating to and holding at that temperature, or below, has little or no effect upon the creaming of milk or the production of a satisfactory cream line. If heated to above that temperature the cream rises slowly and incompletely. It becomes first noticeable at about 146° and of distinct influence at 147° or 148° F. Hamill (1923) states "in milk pasteurised at a temperature of 148° F. the cream line may be decreased by 40 per cent." If therefore in the holder the milk is held at these higher temperatures, as it may be under the definition, the milk will show less cream to the naked eye. Milk distributors attach great importance to a good cream line and this fact has influenced the decision in the U.S.A. to work at a lower

temperature than in England, but one which is yet considered effective. Orla-Jensen (1928) raises the point that while the creaming power has no physiological significance *per se* the agglutinins which he considers as the cause have certain functions which may be of physiological importance. This is a theoretical consideration and at present we know no evidence that it is of any weight. The practical importance of the cream line rests upon the fact that temperatures which diminish it are likely to be evaded by the milk distributor unless there is strict control. A margin of safety is absolutely necessary under practical working conditions, but there is room for further investigation as to whether the present standard temperature requirements need to be maintained precisely in the present form.

### TYPES OF "HOLDER" PASTEURISERS.

While there are many individual types they all can be classified into one of three groups.

#### A. *Vat or batch pasteurisers.*

The simplest type, the milk being heated, held and, if so required, cooled in a single receptacle. An adequate cover and a milk agitator are essentials. The vat is jacketted, the milk being heated by hot water or steam to the required temperature, while the cooling can be done by circulating cold water. A mercury thermometer is usually fitted but a recording thermometer can be substituted. The milk is maintained at the required temperature for 30 min., then rapidly cooled, preferably not in the vat. I have seen a number of batch pasteurisers at work and tested their efficiency and it is quite possible to get complete compliance with the regulations and excellent bacteriological results. This type is especially valuable for the small trader as it is made in small sizes, 50 to 200 gallons capacity. The defects of this type are obvious in that so much depends on efficient management, particularly as regards the time of holding and thorough sterilisation between usage. Pumps, pipes, etc. used for raw milk are rather liable to be used without sterilisation for the pasteurised product.

#### B. *Separate heater with separate holder tanks.*

This is the type commonly met with in medium and large sized dairies. After raising to the required temperature in the heater the milk is retained for the requisite time in the holder tanks. The latter are of many types, but all are supposed automatically to discharge the milk at the end of the holding time. Proper covers and automatic discharge timing apparatus are essentials, while the holders should be jacketted and agitators provided. The defects are discussed below.

In larger plants more complicated arrangements on the same principle are employed. A plate form of heater is often used. In some types the heated milk prewarms the oncoming milk. The milk should throughout be kept from air contact, while heating the milk by hot water is preferable to steam. The

movement of the milk may be on the vacuum system or by pumps. Pasteurisers of this type are expensive, but scientifically they meet every requirement.

### C. *Flow retarders.*

Heated milk which moves on slowly through a system so that it is retained for 30 min. at the standard temperature complies theoretically with the regulations. Pasteurisers of this type are described, but I have never seen one. It is difficult to accept the view that all the milk is held at the temperature required since, as Seligman (1932) remarks, "it has been established that it is wrong to assume that a liquid flowing continuously through a conduit necessarily has a velocity at all points proportionate to the cross section of the conduit."

In a recent paper Frank, Moss and Le Fevre (1932) mention that pasteurisers of this type are being marketed in the U.S.A. and some of their experiments suggest that they may be satisfactory. In the newer types they state "this type of pasteuriser consists of a thermostatically controlled flash heater, the milk from which passes through a regenerator, then into a set of holder tubes designed to give a total holding period of 30 min., thence back into the regenerator, and finally to the cooler and bottle filler." In the newer types the heating coils are distributed to various parts in the holder and governed by thermostatic control.

Judging from the plants which have been seen it is evident that the production in this country of efficient pasteurisers has reached a very high standard. Granted an output of sufficient volume from a dairy very satisfactory pasteurisers can be installed which meet every reasonable requirement. It has, however, to be remembered that the interests of the community are against the concentration of all milk pasteurisation in the hands of a few people. A satisfactory pasteuriser within the means of the comparatively small distributor is a desirable and necessary thing. Sympathetic attention should be given from the Public Health side to this point of view and requirements of unnecessary stringency should not be imposed. Fortunately there are good types of pasteurisers which are not very expensive and which, given intelligent usage, yield excellent results.

## Defects and their control in "holder" pasteurisation plants.

Much may be learned from the experience of America. Pasteurisation was enforced there in many areas before there was adequate realisation that the plant might show inherent defects. In consequence much pasteurised milk was derived from plants showing serious defects resulting in ineffective pasteurisation and a false sense of security. During recent years this technical problem has been recognised and we owe to workers in the U.S.A. much valuable work upon possible defects, upon the proper way to eliminate these defects, and directions as to the control necessary over pasteurisation. In this country practical experience is much more restricted.

The main defects in the actual pasteurisation equipment which may be found and which have to be guarded against are the following:

*Leakage through faulty valves.*

If the leakage is such that either inadequately heated milk or milk held for an insufficient time is passed out as pasteurised, this is a serious defect. Much more common is leakage from the holder, which does not matter if such milk is separately collected and not treated as pasteurised. Significant valve leakage does not seem common in modern plant. In the U.S.A. flush type leak protector outlet valves are usually required.

*Foam in the holder system.*

The foam usually is below the temperature of the milk itself. Whittaker, Archibald, Leete and Miller (1927) studied this subject and often found the foam (which varied from 1 to 4 in. in thickness) 8° to 12° F. below the temperature of the milk. With pre-heated milk at the end of the holding process the average bacterial content of the milk was 16,000 bacteria per c.c. and that of the foam 130,000 per c.c. With vat-heated milk and foam the counts were 13,000 and 76,000 respectively. Although the bacterial count of the milk decreased during the holding process, 66·7 per cent. of the foam samples gave a higher bacterial count after holding than before holding. The bacterial count of foam showed a wide variation taken at different locations in the same vat. Incidentally in nearly all the tests the foam was higher in butterfat than was the milk.

Foam is a defect rather difficult to obviate entirely, since the cause is mainly outside the pasteuriser itself, but a plant which shows any considerable amount of foam should not be passed. The U.S.A. Public Health Service Milk Code 1931 goes so far as to require:

"If foam is present in the holders of vat or pocket types, means shall be provided and used which will keep the atmosphere above the milk at a temperature equal to at least the legally required pasteurisation temperature during the heating and holding periods. If steam is admitted into the holder, the steam line shall be provided with a trap properly designed to avoid the discharge of water into the milk."

*Dead ends in holder outlets.*

If any part of the milk is held in pipes which are not heated or in which the milk is not kept at the required temperature, some milk will escape efficient heat treatment.

*Other defects.*

Inadequate arrangements for temperature and time control are very important defects and suitable requirements must be included in any specification. They are, however, more conveniently discussed under inspection of plant.

The Local Authority responsible for giving a licence to sell pasteurised milk should furnish definite specifications as to what is necessary for a plant to be passed.

*The control of pasteurisation in practice.*

In view of the many possible defects in equipment and in management which may occur, the efficient control of pasteurisation as a technical process assumes considerable importance.

The first point in control is to be satisfied that the whole of the pasteurisation equipment itself conforms to the specification indicated above.

The next point is a study of its efficiency under practical working conditions. This includes the general arrangements of working, the suitability, accuracy and use of proper temperature recorders, testing the time mechanisms and its control, and checking the understanding of his job by the man in charge. These points demand a little more elucidation.

Under general arrangement may be mentioned as to whether there is proper room for the apparatus, and particularly if all of it is under the direct vision of the man in charge. A recent outbreak of 457 cases of paratyphoid fever in Canada (*see* McKay, Currey, McNabb and Berry, 1932), spread by milk supposed to be pasteurised but which was not, was probably due to the opening of the wrong valve and the passage of unpasteurised milk, both of which were made possible because of a faulty lay out.

Particular attention should be paid to the way the first batch of milk is treated. Some "holder" pasteurisers I have seen at work have no means of heating the holder but rely on insulation to keep the temperature from falling more than a degree or so during the 30 minutes' holding. This works correctly enough when the milk is turned into a hot holder, but if the first batch is emptied into a cold holder (as I have known it done as the regular practice) the actual temperature of holding will be below that authorised. In holders not supplied with steam or hot-water pipes the vat itself must be heated by previous passage of hot water to get the required temperature. A hot-water jacket is a better plan. Heulings (1924) as long ago as 1923 pointed out this need.

The temperature recording apparatus requires special attention and in my experience is often faulty. Under equipment we must include an indicating thermometer to record the actual temperature of pasteurisation to be placed, if there are separate heater and holder, on the heater and if of vat type connected with that, to register the temperature in the vat.

The indicating thermometer should be a mercury one, and the operator should be instructed that this is the one he should use to get his temperature and that he should not consult the recording thermometer. This indicating thermometer must be of approved type and size so that the temperature is readily readable and fixed where it is readable. The scale range should be 130–210° F., as in the U.S.A. Code, and accurate within half a degree.

A separate recording thermometer must be included which automatically records upon the usual charts the temperature of the milk all the time the milk is being held. It should also record the time the milk is held. This recorder must be of approved pattern. A point is often made that it should be

in a box which is capable of being locked to avoid tampering, but that is of little importance as tampering is so much more easily done elsewhere.

Equal in importance to noting the presence of an efficient recording apparatus is to test its accuracy. To do this the inspector must be supplied with his own accurate thermometer. He must check the accuracy of both the indicating and the recording thermometers against this and against one another. If the recording thermometer is reading accurately, then it is worth while checking the paper records as regards date, temperature and time of holding. One chart should be used for each day and be signed by the operator in charge.

During an actual run the inspector will look for leaking valves and ascertain if there is an undue amount of foam. He should further notice if the authorised operator is in charge and definitely satisfy himself that this operator knows he is in charge and is responsible. This is a defect in English practice in my experience. Often the manager assumes responsibility and the operator refers the inspector to him. The knowledge and understanding of the man in charge should be verbally tested and his interest aroused. If the installation is of single vat type the inspector should see that there is absolute disconnection during the heating, holding and emptying from the raw milk supply and from the outlet pipe during the first two stages. The vat must be properly covered[1].

The inexperienced in this work may be inclined to suggest that this elaboration of temperature testing is unnecessary and that there are the charts to show the temperature. Unfortunately I have yet to find a recording instrument in use that could not by a trifling alteration be made to read the temperature I wanted, so as to record very neatly the authorised temperature, whereas in reality the true reading should be several degrees lower; thus relieving the operator of the bugbear of possibly passing through a milk which failed to give a good cream line. A good inspector is one who minimises temptation.

The time mechanism of the holder part is usually accurately set for the 30 min., but I have on occasion found the arrangement such that the operator could alter it at will.

One candid operator did inform me that he found it useful, as sometimes the last batch had to be dispatched quickly. This can only pass unnoticed if the recording chart is of the type which does not also record the length of time the milk is held. For the vat type of holder the time duration can be taken by a watch.

The cooling of the milk is included in the definition, so is really part of the pasteurisation process. Great attention should be paid to the position of the

[1] The importance of these points is stressed in the U.S.A. Code and very detailed requirements laid down which would take too much space to reproduce. They are largely the work of Mr L. C. Frank of the U.S.A. Federal Department, whose experience on these matters is unrivalled. I had the opportunity in Washington in 1932 of a long discussion with him on the various technical points and hearing his explanation of the need for such precise directions.

cooler in the depôt and to the cleanliness and the method of sterilisation of this part of the system. The ordinary open face cooler has many defects and is gradually being replaced by a better technical device.

The frequency of the inspections required will depend upon the efficacy of the whole installation and of the qualifications for the job of the man in charge. The inspector should of course be an educator as well as an inspector and a few visits in that capacity should greatly improve the efficient working of the plant. The persistence of most defects is mainly due to ignorance.

There is one further possibility of error which has not yet been considered, *i.e.* the human factor. This is capable of spoiling results from the most perfect equipment and with the most elaborate paper instructions. I do not know of any means of controlling faulty work through an incompetent operator short of almost daily inspection, which of course is impracticable. For this reason I favour making it a requirement that all operators of pasteurisation plant should be licensed. This would give very considerable control. No one would be given a licence unless passed as a satisfactory operator and the detection of faulty working might involve its suspension. I do not suggest any high standards of requirement, since we do not want to create a privileged class with corresponding high wages, but the fact that a licence (given by the Local Authority) was necessary would exert a very steadying influence. It is rather absurd to make stringent requirements as to the type of apparatus and how it is to be worked and then leave it to anybody to operate it.

From the above it will be seen that I suggest as necessary that the plant must be approved before a licence is given, that the inspectors must be trained in inspection, that the amount of inspection given must be adequate and that the actual trade operator should be licensed.

## Bacteriological standards for pasteurised milk.

The place of bacteriology in connection with the control of pasteurisation or as a means of judging its efficacy is a problem involving complex issues.

The requirement of the Ministry of Health is:

"On a sample of milk being taken at any time after pasteurisation and before delivery to the consumer, the milk shall be found not to contain

(*a*) more than 30,000 bacteria per c.c., nor

(*b*) any *Bacillus coli* in one-tenth of a c.c."

Such a standard is merely one which aims at controlling to some extent the conditions under which pasteurised milk is vended. It bears no close relationship to the technical efficiency of the pasteurisation process, since it is complicated by and influenced by the factor of multiplication of bacteria subsequent to pasteurisation. To sample pasteurised milk as it leaves the cooler and apply such a standard, and be satisfied if the milk conforms to it, as is often done, is merely ridiculous. The standard is lenient because it has to allow for multiplication.

Put another way, such a standard is affected by two different sets of factors, *i.e.*

(i) The efficiency of pasteurisation as a technical process.

(ii) The care of the milk subsequent to pasteurisation right up to the time it reaches the consumer, and this is influenced by the chances of subsequent contamination and by the multiplication of bacteria in a nutrient medium.

I am somewhat doubtful of the value of any standard of pasteurised milk as delivered to the consumer, but it is some check on the care given to the milk. It is no evidence that pasteurisation has been efficiently performed, *i.e.* that the milk is free from pathogenic organisms.

Quite a different question is as to whether it is possible to judge the efficiency of pasteurisation by bacteriological standards for pasteurised milk which are capable of ready applicability. The only satisfactory test of any particular batch of milk pasteurised is that tubercle bacilli have failed to survive, but this is not a practical routine test.

On the other hand, properly devised tests should be of assistance in judging the working of any particular plant, if we can agree as to the tests to apply.

The factors affecting the bacterial content *immediately* after the pasteurisation process is completed, and assuming efficient pasteurisation conditions of time and temperature, are mainly the following:

(*a*) An initial high bacterial count in the raw milk. Heat destruction is quantitative to a certain extent, while the higher the initial count the greater the liability to have present heat resistant types. At the same time any standard based on a percentage reduction is in my opinion most unsatisfactory.

(*b*) An unusually high proportion of resistant types. Organisms which resist efficient pasteurisation are sporing bacteria (aerobes, anaerobes, thermophils) and some micrococci, all so far as is known non-pathogenic. In addition there are found at times highly resistant strains of types which are for the most part of low resistance. Highly resistant *B. coli* strains, for example, are recorded (Ayres, 1932, and others). At times, according to American reports, pasteurisation plants have been troubled by the prevalence of such unusually resistant forms.

(*c*) Growth of thermophilic strains in the milk. This has been the subject of a number of investigations[1]. The thermophils are present in the raw milk, increase during the holding of the milk at high temperatures before pasteurisation and in the holder tanks. They are particularly likely to be found in pasteurisation depôts which employ long runs, *i.e.* 5 to 6 hours' duration, without re-sterilisation. For the most part these bacteria are not evident in the standard plate count methods employed in England, but most of the pinpoint colonies on agar places are of this character.

(*d*) Contamination of the milk from the cooler or bottling plant.

[1] See Eckford (1927), Hucker (1928), Prickett and Breed (1929), Yale (1929), Yale and Breed (1930), Mudge and Thorwaldsen (1930), Hansen (1931).

In view of the varied bacterial flora of the raw milk a numerical bacterial standard is not in my opinion a good one to use to judge the efficiency of pasteurisation. If we knew a harmless saprophyte common in milk and with the same heat resistance as the tubercle bacillus and readily enumerated, this would obviously be the basis of our standard. Failing such a strain I consider that lactose fermenters of *B. coli* type best serve our purpose. It is true that their thermal death point is comparatively low and therefore even their complete destruction is no proof that *B. tuberculosis* is eliminated, but on the other hand their survival in any numbers is strong evidence of the inefficiency of the pasteurisation practised. This type of organism has the great advantage of being invariably present and in considerable numbers, in the pre-pasteurised milk.

At present my own results are too few to utilise to suggest a definite standard, but it should be possible to devise a fair standard. For example, *B. coli* should not be present in 10 c.c., probably not in considerably larger amounts. This of course applies to milk immediately at the end of the pasteurisation process, *i.e.* according to definition after the cooling, and this should be the place of sampling. Milk immediately after bottling should give the same results and the sample could consist of such a bottle, if preferred.

Should the milk fail to comply with the standard then it must mean either that the pasteurisation process is inefficient, that there is material contamination in pipes or on the cooler, or that the milk is so heavily contaminated bacterially that it should never have been used at all. All three are conditions which should not be permitted, so the standard is along the lines required.

I can visualise a great field of usefulness for such a test, when one has been properly worked out. Its defect is on the negative side, since a good result does not prove that everything is satisfactory. Bacteriology cannot take the place of efficient inspection of the plant.

It is evident that the technical problems involved in pasteurisation are numerous and many of them are of importance. If designated pasteurisation is practised extensively these technical questions cannot be ignored. This is one reason why there are great advantages in the gradual introduction of legal pasteurisation in this country. In my proposals as set out elsewhere (Savage, 1931), among other things I recommend:

(i) That permissive powers be granted to the larger Urban areas to require that all milk coming into the area be efficiently pasteurised, or be from tuberculin tested herds. This permissive power to be only granted after an inquiry by the Ministry of Health, who would have to be satisfied that the necessary technical problems could be adequately dealt with. A time limit would be necessary to allow of any adjustments.

(ii) The prohibition of all forms of heat treatment, other than efficient pasteurisation, for liquid milk coming into the approved Urban area. No milk to be pasteurised twice.

It will be evident that important implications are involved in these sug-

gestions. The scheme would not be put into operation all over the country at one time but by a gradual extension enabling the technical side to keep pace with requirements. In areas adopting it a breathing time would be allowed to enable the smaller distributors to adjust themselves to the new requirements; for example, by providing a pasteurisation plant in common or by converting their herds into herds of tuberculosis free animals. The prohibition of other heat treatment will have a most beneficial influence on cleanly production since dirty milk may not travel and remain marketable. The pasteurisation plants must be in the towns, since only there can the process be efficiently supervised.

These proposals are similar to those subsequently adopted by the Special Committee of the People's League of Health and included in their Report (1932: *A Survey of Tuberculosis of Bovine Origin in Great Britain*).

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*Note.* Important papers not specifically mentioned include the following:

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