Certain Biological Factors Related to Tallowiness in Milk and Cream

By P. H. Tracy, R. J. Ramsey,
and H. A. Ruehe

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Certain Biological Factors Related to Tallowiness in Milk and Cream

By P. H. TRACY, R. J. RAMSEY, and H. A. RUEHE[1]

BOTH producers and distributors have spent considerable effort in improving the bacterial quality of city milk supplies. Thru the adoption of milk grading systems and the establishment of sanitary inspection services the bacterial quality of raw milk has been greatly improved. Coincident with this improvement, however, there has been an increasing tendency for bottled milk to have a tallowy flavor. Tho in most of the instances of this flavor defect brought to the attention of the authors, metal contamination has been found to be an important cause of the difficulty, the present greater occurrence of tallowiness cannot logically be attributed entirely to this cause. There probably is but little more opportunity for metal contamination to occur now than formerly, and as a matter of fact, some of the most troublesome cases of tallowiness have been found to occur in those plants where special efforts were made to reduce the amount of copper and iron contamination to a minimum. This suggests that there is some factor other than those already studied that is related to the development of this off-flavor.

In an earlier study Tracy and Ruehe[11]* found that tallowiness in market milk was more common in winter than in summer. They also noted that the tallowy flavor developed to a greater extent when the milk containing metallic salts was stored at 40° F. than when stored at 68° F. These observations led to a further study of the problem, the results of which are set forth in this publication.

Definition of Tallowiness

The confusion in the literature in the matter of flavor nomenclature has made it difficult to correlate the work done on tallowiness in dairy products by the different investigators, both in this country and in Europe. Tallowiness has been described in various ways, possibly because of the different degrees of development that may occur. Such terms as oily, cappy, papery, astringent, and metallic have been used. Tallowiness is recognized as a defect due to the oxidation of the butter fat. Not only is the oxidized fat flavor modified by the intermediate

[1]P. H. TRACY, Associate Chief in Dairy Manufactures, R. J. RAMSEY, Assistant in Dairy Manufactures, and H. A. RUEHE, Chief in Dairy Manufactures.

and end products formed, but it is also influenced by the presence of certain metallic salts which may be detected by taste before the true tallowy flavor is evident. This fact undoubtedly has led to the use of different terms in the description of this defect.

Flavors caused by fat oxidation should not be confused with those flavors, commonly called rancid, that are brought about thru fat hydrolysis. It is evident from studies conducted by the authors that the reaction responsible for hydrolysis is progressive, intermediate products being formed that give different taste reactions. Samples of raw milk having a normal flavor when freshly drawn from the udder may sometimes acquire a "cowy" taste upon storage. This defect later develops into the characteristic rancid flavor and finally reaches a degree of development in which a soapy flavor predominates. Oxidation-reduction potential measurements indicate that oxidation plays no part in the formation of these flavors. That the reaction is hydrolysis is suggested by the increase in titratable acidity that occurs simultaneously with the development of the flavor. Milk evidently contains an enzyme or other substance responsible for the reaction, since heating the milk to 142° F. renders the agent inactive. Homogenizing the raw milk at low temperatures (90-100° F.) hastens the reaction and intensifies the defect, possibly because in the homogenized milk a greater fat surface is exposed to the agent responsible for the hydrolysis. Furthermore, an antagonistic reaction between the agents of tallowiness and rancidity in raw milk containing copper salts has been shown to exist. This antagonistic reaction makes it necessary in flavor studies to pasteurize samples of milk and cream so as to destroy the cause for rancidity in order to produce a tallowy flavor.

Another flavor defect that may be confused with tallowiness is the flavor caused by the action of sunlight upon milk proteins. Tracy and Ruehe[11*] have shown that a short-time exposure of milk in uncolored glass bottles to sunlight will result in the characteristic tallowy flavor. As the time of exposure of the milk to sunlight is increased, however, a point is eventually reached where the tallowy flavor is overshadowed by a burnt flavor. Metallic salts are not a factor in this reaction. Skim milk and low-fat milks develop more pronounced burnt flavors than whole milks or cream. Tracy and Ramsey[10*] have studied a similar flavor defect in cottage cheese. A disagreeable burnt flavor was shown to result from the exposure of cottage cheese in uncolored glass containers to either direct or indirect sunlight, the flavor being more pronounced in the curd exposed to direct sunlight. The defect was not so highly developed in the creamed curd as in the plain curd. The occurrence of a more pronounced flavor in the plain curd is contrary to the result expected if the flavor were due to the oxidation of butterfat.

In the production of tallowiness oleic acid is thought to be the main constituent concerned. This unsaturated fatty acid has the ability to combine with oxygen to produce aldehydes and acids, some of which have the characteristic tallowy flavor and odor. The butterfat does not become oxidized immediately but passes thru an induction period during which there is practically no absorption of oxygen. The duration of this period depends upon such factors as the amount of oxygen present, heat, light, acidity, and the presence of certain metals such as copper and iron. It thus becomes apparent that the problem of tallowiness in dairy products is related to those procedures which may affect the length of the induction period that precedes the rapid absorption of oxygen by the fat. The term tallowiness will be used in this bulletin to refer only to those flavors that result from such reactions.

Relation of Incubation of Milk After Contamination With Metal to the Development of Tallowiness

When tallowiness occurs in market milk, the first milk thru the system usually has the most noticeable off-flavor, which is undoubtedly due to the fact that the soluble metal oxids which form on the plant

TABLE 1.—INCUBATION OF PASTEURIZED MILK AS A RETARDER OF TALLOWINESS

Milk held at—	Degree of tallowiness	Bacterial count per cc.
40° F. for 12 hrs.	+++++	200
80° F. for 2 hrs., 40° F. for 10 hrs.	+	600
80° F. for 4 hrs., 40° F. for 8 hrs.	−	15 000
80° F. for 6 hrs., 40° F. for 6 hrs.	−	32 000
		Methylene blue reduction
40° F. for 24 hrs.	+++++	10 hrs.
68° F. for 2 hrs., 40° F. for 22 hrs.	+++	9 hrs.
68° F. for 4 hrs., 40° F. for 20 hrs.	+	6 hrs.
68° F. for 6 hrs., 40° F. for 18 hrs.	−	5½ hrs.

equipment between runs are to a great extent removed by the first milk coming into contact with the metal surfaces. It has been demonstrated many times that during the winter months a sample of the first milk bottled each day at the University of Illinois creamery, when held at 40° F. for 24 hours, will become tallowy, whereas a companion sample held at room temperature two or three hours and then placed at 40° F. will have little or no tallowiness 24 hours later. Representative data are given in Table 1. The milk used was the first of a day's run (200 gallons) bottled at the University creamery.

Raw milk to which a copper salt had been added was found to respond to incubation in the same way as pasteurized milk.

Relation of Incubation of Milk Previous to Contamination With Metal to the Development of Tallowiness

As previously mentioned, a tallowy flavor in pasteurized University milk was not noticeable in the summer but was usually pronounced during the winter. This was particularly true of the first milk run thru Benedict nickel internal tubular coolers. This condition was partially corrected by eliminating the Benedict nickel coolers and passing the hot milk over a new tinned copper surface cooler. However, even in this case, enough metal was apparently added by passage of the milk thru sanitary pipe lines and thru a bronze piston pump to cause the first milk bottled during cool weather to acquire a distinct tallowy flavor after being held at 40° F. for 24 hours. The defect was much worse during extremely cold weather. With the return of milder outdoor temperatures, the tallowy flavor would be less noticeable and with the arrival of warm weather would disappear entirely. In the fall, however, the trouble would recur.

The apparent correlation between climatic conditions and the occurrence of tallowiness suggested a relation between the extent of biological activity in the raw milk and the tendency of the bottled product to become tallowy. Davies,[2*] working independently in England, has also come to the conclusion that bacteria are a factor in preventing tallowiness, for he states "conditions favoring the development of taint are low temperature of storage and low bacterial count." Kende[7*] believes "oiliness" of whole milk is caused by an oxidizing enzyme in the milk. He also has found that microorganisms will counteract the oxidation reaction, and he advances the theory that a "factor" is formed in the milk which has the power to counteract the action of the enzyme. The theory that bacteria when present reduce the tendency of the milk to become tallowy is further substantiated by the fact that tallowiness seems to be most prevalent in the milk sold by those distributors who are able to control the bacterial quality of their milk from the time of its production until bottled.

In order to determine whether incubation of the milk previous to metal contamination might be a factor in the retardation of tallowiness, a series of experiments was performed by the authors, representative results from which are given in Table 2. The incubation of raw milk previous to contamination with metal proved to be a very important factor in retarding tallowiness. In some cases of incubation the increase in numbers of bacteria, as determined by the plate count, was very slight, yet the retarding effect upon fat oxidation was marked.

TABLE 2.—RELATION OF INCUBATION OF MILK PREVIOUS TO METAL CONTAMINATION TO DEVELOPMENT OF TALLOWY FLAVOR

Treatment of milk[1]	Degree of tallowiness	Bacterial count per cc.
Aseptically drawn—held at 40° F. for 18 hrs.	++++++	15
Aseptically drawn—held at 80° F. for 3 hrs., 40° F. for 15 hrs.	++	100
Drawn from udder into unsterilized utensils—held at 40° F. for 18 hrs.	++++++	6 600
Drawn from udder into unsterilized utensils—held at 80° F. for 3 hrs., 40° F. for 15 hrs.	+	34 000

[1]All samples were exposed to Ambrac metal for 3 minutes at 142° F. three hours after storage at the indicated temperatures.

Variation in Tendency of Milk to Become Tallowy

The addition of equal amounts of copper salt to different milks does not always result in the development of tallowy flavors of the same degree. In such experiments some milks may become distinctly tallowy in 24 hours, whereas others may not taste tallowy even after 48 hours' storage at 40° F. This was found to be true of milks drawn aseptically from the cow's udder as well as of milks selected from the shipments of different patrons delivering milk to the University creamery. The variation in degree of flavor could not be correlated with the percentage of fat present in the milk. This lack of correlation suggests that milks may contain reducing bodies other than bacteria, such as leucocytes,[1] that are a factor in retarding oxidation of the butterfat. The addition of udder tissue was not found to change the intensity of the defect. Davies[2]* suggests that some of the minor constituents of milk, such as lecithin, cholesterol, and the soluble nonprotein materials, react with some of the chemical oxygen, thus causing variations in the degree of fat oxidation.

Yeast Cells as a Retarder of Tallowiness

Bacteria having been found to have the power to retard the development of tallowy flavor in milk, the authors decided to determine to what extent the same effect might be secured by using yeast cells.

[1]Milk may contain several million leucocytes per cubic centimeter.

A heavy suspension of yeast cells was prepared by using Fleishman's yeast cake and distilled water. The suspension was then added to milk in the manner indicated in Table 3.

TABLE 3.—EFFECT OF YEAST CELLS ON DEVELOPMENT OF TALLOWY FLAVOR IN MILK

Method of preparing sample[1]	Degree of tallowiness
Control	++++
Milk with yeast suspension held at 40° F. for 24 hrs.	
1 cc. suspension to ½ pint of milk	–
5 cc. suspension to ½ pint of milk	–
10 cc. suspension to ½ pint of milk	– (slight yeast flavor)
Milk held at 40° F. after yeast suspension heated to 170° F. had been added	
1 cc. suspension to ½ pint of milk	++++
5 cc. suspension to ½ pint of milk	++++
10 cc. suspension to ½ pint of milk	++++

[1]All of the milk contained 2.6 parts of copper per million. In this and all subsequent experiments the copper used was in the form of copper sulfate.

The live yeast cells were found to be very effective retarders of fat oxidation. Heating the yeast suspension to 170° F., however, destroyed the ability of the yeast cells to act in this way. It was not necessary to incubate milk containing live yeast cells in order to prevent the formation of tallowiness; the inoculated samples held at 40° F. did not acquire a tallowy flavor. The filtrate from a yeast suspension was also tested and was found to have no effect in retarding tallowiness.

These data indicate that unless there is an agent formed which is either nonfiltrable or destroyed by heat, it is the metabolism process itself, rather than the end products of metabolism of the cells, that is responsible for the retardation of tallowiness.

The Homogenizer as a Retarder of Tallowiness

According to Davies,[2]* homogenized milk, because of the increased fat surface, is more susceptible to oxidation than unhomogenized milk. In the Illinois studies, however, it was found that milk to which copper had been added was when homogenized less likely to become tallowy than milk to which copper had been added but which had not been homogenized. In passing the milk thru the homogenizer without pressure, the milk apparently became sufficiently contaminated with copper from the machine to cause a tallowy flavor to develop in 24 hours, but with the application of pressure to the milk, tallowiness did not develop in any noticeable degree. When a copper salt was added to the milk at the rate of 2.6 parts per million, the homogenized milk still remained free from tallowiness after 24 hours of incubation altho both the control milk and that to which the copper was added and which was passed thru the machine without pressure were strongly tallowy.

This effect of the homogenizer is thought to be apparent rather than actual. Homogenization changes the physical consistency of the milk, which may affect the taste. When varying amounts of gelatin were added to milk that was contaminated with copper, the degree of tallowiness resulting was found to be in inverse proportion to the amount of gelatin added. Such milk, however, when agitated to reduce its viscosity, became more noticeably tallowy. The addition of gelatin to milk that had already acquired a tallowy flavor caused the flavor defect to become much less apparent. It would seem, therefore, that the effect of homogenization in reducing tallowiness may be due to a difference in the taste reaction rather than to any reduction in the intensity of the oxidation of the butterfat. As shown in the discussion on page 591 the homogenization process has no apparent effect on the oxidation-reduction potential of the milk.

TABLE 4.—EFFECT OF HOMOGENIZATION ON DEVELOPMENT OF TALLOWY FLAVOR IN MILK

Treatment	Degree of tallowiness after 24 hrs. at 40° F.	
	No copper added	Copper added at rate of 2.6 p.p.m.
Control	–	++++
Pumped thru homogenizer without pressure	+++	+++++
Homogenized at 142° F. with 2,000 lbs. pressure on the first valve and 1,000 lbs. pressure on the second valve	–	–

Incubation of Cream as a Retarder of Tallowiness in Butter

Altho the cream used for buttermaking at the University creamery in the winter is more nearly a sweet cream than that used in the summer months, the authors have observed that the summer cream invariably produces a butter freer from metallic and tallowy flavors than butter from the winter cream. It is the usual practice at the University creamery to churn twice each week, using cream delivered by farmers as well as any sweet cream that is left after the needs of the market milk and ice-cream departments have been met. This mixture produces a churning cream of low acidity free from bacterial defects, yet it has a tendency during the winter season to produce a butter with a metallic or tallowy flavor. The cream delivered by farmers, as soon as weighed and sampled, is usually stored at 40° F. in 10-gallon milk cans for one to three days before being prepared for churning. On several occasions churnings composed almost entirely of sweet cream have been found to produce a butter having the characteristic fat-oxidized flavor.

To determine whether incubation of the cream might be a factor in preventing the flavor defect, the writers arranged to have the cream as it was received from the farmers and the surplus pasteurized cream dumped daily into a glass-lined forewarming vat. The cream was kept at room temperature until enough had been received to make a churning. This usually meant storage of the cream for one to three days. With this change of procedure a marked improvement in the quality of butter was noted. For a period of several weeks during the winter this practice of mixing the creams and holding them at room temperature for one to three days was continued, with a resulting improvement in the butter score from the usual 89-90 to as high as 92.

As a result of this practical demonstration of the beneficial effect (from the standpoint of avoiding metallic and tallowy flavors in the butter) of incubating cream to be churned, a series of experiments was conducted under controlled conditions to determine to what extent biological activity in the cream may aid in preventing tallowiness in butter.

In these experiments 40-percent cream direct from the separator was cooled to 70° F. and 2.6 parts per million of soluble copper was added. The cream was placed in five glass milk bottles. One bottle was stored at 40° F. and the remaining four bottles were placed at 68° F. At the end of the first day and each succeeding day one bottle was removed from the 68° F. incubator to the 40° F. refrigerator. At the end of five days all the incubated samples were standardized to .3 percent acidity and all lots were pasteurized in the bottles by heating to 142° F. for 30 minutes. After cooling, the samples were stored over night and churned.

With the above differences in treatment there was a marked difference in the flavor of the creams and a similar difference in the flavor of the butters. The data in Table 5 are representative of the results obtained. The butter made from cream stored continuously at 40° F. was by far the poorest in flavor, being very tallowy. It was evident that excess incubation would also cause a tallowy flavor to occur in the butter. Sometimes one-day incubation was insufficient, whereas holding the cream at about 70° F. for two days prevented the tallowy flavor from occurring in the fresh butter.

It should not be construed from the above findings that proper cooling and storing of cream to be made into butter is of no value. As a matter of fact, the incubation of cream when the cream was not contaminated with metal was of no benefit. The data, however, do offer a possible explanation for the fact that practical buttermakers often have difficulty, particularly in the winter or during cool weather,

TABLE 5.—EFFECT OF INCUBATION OF CREAM ON DEVELOPMENT OF TALLOWY FLAVOR IN BUTTER

Cream held at—	Acidity in cream before neutralizing	Score of butter 1 day old
	perct.	
40° F. for 5 days	.13	87 (very tallowy)
68° F. for 1 day, 40° F. for 4 days	.40	90.5 (good)
68° F. for 2 days, 40° F. for 3 days	.50	90.5
68° F. for 3 days, 40° F. for 2 days	.55	89
68° F. for 4 days, 40° F. for 1 day	.60	88.5 (slight tallowiness)

in making a good grade of butter from surplus sweet cream obtained from milk and ice-cream plants. Such cream is probably sufficiently contaminated with metal from vats, sanitary pipe lines, coolers, storage cans, and the like, to become tallowy upon storage at 40° F., yet this same cream, if held for a short time at a temperature high enough to encourage the growth of lactic acid bacteria, would probably produce butter with a higher score, or at least with less metallic or tallowy flavor, than if not so treated.

Relation of Oxidation-Reduction Potential to the Development of Tallowiness

From the data already presented it is to be concluded that organisms growing in milk or cream have the power, in some way or other, to prevent or retard the development of tallowiness. This biological action may be explained in various ways. On the basis of phagocytosis the bacterial or yeast cells might be assumed to have the power to surround the small metal ions, thus removing them from the field of action and preventing them from exerting their catalytic activity. Such a course, however, does not seem likely because of the physical state in which the metal exists in the milk. That the action is not due to an antioxidizing substance formed thru metabolism was shown by the failure of a filtered or heated yeast cell suspension to prevent the formation of tallowiness. It is more logical to believe that the bacteria and yeast function thru their removal of oxygen from the milk.

Davis[3]* explains the action of bacteria as one by which the oxygen is removed not only by respiratory processes but by the production of systems that are capable of inducing a high-reducing intensity.

Thornton and Hastings[9]* have reported that milk has reducing properties as it comes from the udder, and Skar[8]* has suggested that the leucocytes may play an important role in causing a reducing potential. The part that these cells play in the reducing of milk in the reductase test is well known. Coulter[1]* has observed the reducing properties of sterile bouillon and ascribes this to a removal of molecular oxygen.

Bacteria differ widely in their ability to induce low reducing potentials. Hewitt[6]* believes that this ability depends upon the ease with which the organisms form peroxid and catalase. Peroxid-forming organisms such as pneumococci and haemolytic streptococci are not able to induce extremely low potentials. The formation of catalase, according to Hewitt, prevents the complete dying off of organisms which results from the formation of peroxids, thus maintaining a reducing potential. Frazier and Whittier[4]* have studied the effect of various pure cultures on the oxidation-reduction potential of milk. They found that each organism produced potentials characteristic of that particular species. In another study[5]* they found that *Escherichia coli, Escherichia communior,* and *Aerobacter arogenes* when grown with streptococcus lactis, all exerted a restraining influence upon the rapid drop in Eh values usually caused by pure cultures of streptococcus lactis.

Method of Measuring Oxidation-Reduction Potential

To determine to what extent the oxidation-potential reading of milk might be correlated with certain flavor changes, a series of experiments was performed to study the significance of those factors already found to be related to the development of tallowiness.

The potentials were determined by observing the E.M.F. exerted on bright platinum electrodes, using a saturated KCl calomel cell as the reference electrode. The burnished platinum foil electrodes were one centimeter square and .003 inch thick. Connections were made from the reference electrode to the samples under measurement by means of a saturated KCl liquid junction and saturated KCl agar bridges. Potential readings were reduced to the conventional hydrogen scale. A Leeds and Northrup Type K potentiometer and a sensitive galvanometer were used to measure the E.M.F.

Oxidation-Reduction Potential of Milk

The variation in the oxidation-reduction potential of milk subjected to certain conditions previously found to affect the development of tallowiness is shown in the data in Tables 6, 7, and 8.

In Table 6 are the measurements taken on mixed cows' milk of the University herd. In comparing the Eh value of the milk held at 70° F. for 5 hours, and then stored at 40° F., with the measurements made of some of the same milk held at 40° F. continuously, it will be noted that the reading on milk held at 40° F. continuously changed

TABLE 6.—OXIDATION-REDUCTION POTENTIAL OF MIXED COWS' MILK

Time elapsing after setting sample	Samples stored at 70° F. for 5 hrs., 40° F. for 14 hrs.		Samples stored at 40° F. for 19 hrs.	
	Control	Copper added—2.6 p.p.m.	Control	Copper added—2.6 p.p.m.
hrs.	Eh	Eh	Eh	Eh
½	.29402	.32291	.30730	.30987
1½	.28795	.33864	.31315	.30721
2½	.27878	.37288	.31262	.30342
4	.25630	.34756	.31226	.30150
5	.25980	.37105	.30420	.29877
6	.26390	.37016	.30337	.39891
19	.15837	.28208	.30242	.43803
Degree of tallowiness after 24 hrs.	−	−	−	+++++

very little while the reading on the milk held at 70° F. made almost a continual drop from the first hour on. The presence of copper changed the potential toward the oxidation side very noticeably in the case of the milk stored at 40° F., while the effect was less pronounced in the milk stored at 70° F., in which sample there seemed to be two forces working, one in the direction of oxidation and the other in the direction of reduction.

A more detailed study of potential changes in milk, as brought about by metal contamination and storage temperature variations, is shown by the data in Table 7. Here again it is seen that the milk, upon storage, gradually changed in potential toward the reduction side, the drop being lower in the milk stored at the higher temperature. The introduction of a copper salt, however, caused the potential to swing toward the oxidation side, the milk held at the lower temperature giving the higher reading.

As might be expected, there was a greater drop in the milk held at 90° F. for 5 hours than in the milk held at 80° F. for 3 hours, while milk held at 90° F. for 5 hours and then at 80° F. for 3 hours had the greatest drop of all. The incubation of the milk at 90° F. before storage at 40° F. caused a greater decrease in potential than when the milk was stored at 40° F. without incubation. This rapid decline in potential was only slightly checked by the addition of the copper; which fact indicates that incubation starts a reduction action that continues for some time after the temperature is lowered to a point that is expected to stop bacterial reproduction. This offers a possible explanation for the great difference between the tendency of summer milk and winter milk to become tallowy.

The data in Table 7 show rather conclusively that the rapid development of a tallowy flavor in milk may be brought about by the

TABLE 7.—OXIDATION-REDUCTION POTENTIAL OF MILK FROM AN INDIVIDUAL COW

Time of reading	Milk held at 40° F. for 5 hrs., then treated as below				Milk held at 90° F. for 5 hrs., then treated as below			
	Control		Copper added—2.6 p.p.m.		Control		Copper added—2.6 p.p.m.	
	Held at 40° F. for 24 hrs.	Held at 80° F. for 3 hrs., 40° F. for 21 hrs.	Held at 40° F. for 24 hrs.	Held at 80° F. for 3 hrs., 40° F. for 21 hrs.	Held at 40° F. for 19 hrs.	Held at 80° F. for 3 hrs., 40° F. for 16 hrs.	Held at 40° F. for 19 hrs.	Held at 80° F. for 3 hrs., 40° F. for 16 hrs.
hrs.	Eh	Eh	Eh	Eh	Eh	Eh	Eh	Eh
5	.28346	.28372	.28755	.27630	.26526	.23607	.27168	.25125
6¾	.28206	.26996	.28059	.30075	.24530	.17984	.23820	.20262
10¼	.27560	.26787	.28262	.29846	.23095	.17278	.22617	.18109
13¼	.27297	.26630	.28745	.29663	.22751	.19677	.20630	.16325
24	.27166	.26416	.33246	.31180	.15408	.09127	.19728	.12429
Degree of tallowiness after 24 hrs.	–	–	+++ ++	+++	–	–	–	–

presence of a catalyst such as copper, and that incubating the milk at 80° to 90° F. may result in a retardation of the oxidation. In these tests the potential of milk containing added copper held at room temperature would sometimes change rapidly at first towards the oxidation side and later swing back towards the reduction side sufficiently to prevent the tallowy flavor. This condition is possibly due to the ability of the copper salts to catalyze oxidation reactions more rapidly at first than the metabolism of the bacteria can cause the reverse reaction to occur.

The data in Table 8 show how the presence of yeast cells affect the potential, bringing it well below .3000 Eh, which seems to be the approximate point above which tallowy flavors are likely to occur. The drop in the potential to .26830 Eh of the milk containing the copper and held at 80° F. for 3½ hours, followed by a rise to .33483 Eh 4 hours later, probably accounts for the fact that this sample was slightly tallowy after 24 hours.

TABLE 8.—EFFECT OF YEAST ON THE OXIDATION-REDUCTION POTENTIAL OF RAW MILK

Time elapsing after setting sample	Samples held at 80° F. for 3½ hrs., 40° F. for 8 hrs.		Samples held at 40° F. for 11½ hrs.		
	Control	Copper added—2.6 p.p.m.	Control	Copper added—2.6 p.p.m.	Copper—2.6 p.p.m.—plus yeast
hrs.	Eh	Eh	Eh	Eh	Eh
½	.31397	.32108	.33460	.33471	.33353
1½	.29303	.33132	.31846	.33573	.32186
3½	.27867	.30793	.31345	.33080	.31462
5½	.27287	.29960	.30960	.33595	.31600
7½	.25703	.26830	.30755	.36394	.31987
11½	.25161	.33483	.29494	.35970	.27096
Degree of tallowiness after 24 hrs	−	+	−	+++	−

A comparison of the Eh value of homogenized milk with that of unhomogenized milk is shown in Table 9. The milk pumped thru the homogenizer had practically the same increase in Eh regardless of whether or not it was subjected to pressure. This was true of the milk to which the copper was added as well as of the control samples. Apparently enough metal contamination occurred in passing thru the homogenizer to catalyze the oxidation process, resulting in an increase of Eh toward the oxidation side. The close relationship between the Eh value of the homogenized and unhomogenized milk indicates that the lessened intensity of the tallowy flavor developing in homogenized milk needs to be explained in some other way than on an oxidation-reduction basis.

TABLE 9.—EFFECT OF HOMOGENIZATION ON THE OXIDATION-REDUCTION POTENTIAL OF FRESHLY DRAWN MILK PASTEURIZED AT 142° F. FOR 30 MINUTES

Time elapsing after setting sample	Control (no copper) (40° F.)			Copper added—2.6 p.p.m. (40° F.)		
	Control	Passed thru homogenizer no pressure	Homogenized 2 500 lbs. 1st valve, 1 000 lbs. 2d valve (135° F.)	Control	Passed thru homogenizer no pressure	Homogenized 2 500 lbs. 1st valve, 1 000 lbs. 2d valve (135° F.)
hrs.						
¾	.26448	.26500	.26495	.26650	.27026	.27003
5¾	.26167	.26610	.26485	.26497	.28136	.28079
16¾	.25973	.28237	.28445	.28526	.32329	.32558
Degree of tallowiness 24 hrs. after setting	−	++++	+	++++	+++++	+

Oxidation-Reduction Potential of Cream

As previously noted, incubation of cream contaminated with metal at temperatures high enough to permit bacterial growth was found to improve the flavor of butter made from the cream as compared with the flavor of butter made from some of the same cream stored at 40° F. Eh measurements of such cream revealed much the same situation as exists in the case of milk (Table 10). With incubated cream,

TABLE 10.—OXIDATION-REDUCTION POTENTIAL OF RAW CREAMS CONTAINING 35 PERCENT BUTTERFAT

Time elapsing after setting sample	Eh measurements of cream (copper added—2.6 p.p.m.)	
	Held at 40° F.	Held at 90° F.
hrs.		
½	.28555	.27443
3½	.31124	.23264
5½	.33191	−.02429
7	.34824	−.11039
24	.37662	−.08961
48	.36708	−.10553
96	.34951	−.10585
120	.31786	−.10555
144	.28040	−.10693

Butter scores (one day after manufacture)

Butter made from cream held at 40° F. for 5 days	86.5
—at 90° F. for 1 day, 40° F. for 4 days	90.5
—at 90° F. for 2 days, 40° F. for 3 days	90.0
—at 90° F. for 3 days, 40° F. for 2 days	89.5
—at 90° F. for 4 days, 40° F. for 1 day	89.0 (slightly metallic)
—at 90° F. for 5 days	89.0 (slightly metallic)

however, the Eh values dropped well below the positive side. After the second day there was practically no change in Eh reading, a fact which suggests a change in the nature of the biological activity in the cream at that time. The quality of the butter also became less desirable at this point. In studying the Eh values of the cream held constantly at 40° F., a maximum oxidation about the end of the first day was noted, after which the potential moved toward the reduction side. This phase of the study deserves further investigation, for it suggests the possible application of Eh measurements in the laboratory control of commercial butter manufacturing processes.

Summary

Data presented in this study show that milk contaminated with a copper salt is more likely to become tallowy if stored immediately at 40° F. than if held at higher temperatures (68°-90° F.) for 1 to 6 hours before being placed at 40° F. It was also found that milk incubated previous to contamination with metal is less likely to become tallowy than milk cooled immediately to 40° F. after being drawn from the udder of the cow. Milks from individual cows differed in their tendency to become tallowy. This difference is thought to have been due to cells or other antioxidizing substances contained in the milk.

Living yeast cells retarded the development of tallowiness in milk stored at 40° F. Dead cells or the filtrate of a yeast suspension had no such effect.

Homogenization was found to retard the development of a tallowy flavor in milk. This retardation is thought to have been due to certain physical change in the milk which made it less possible for the judge to detect the development of tallowiness organoleptically.

Incubation of cream to which copper had been added raised the score of the butter 3.5 points. Holding the cream at room temperature for one to two days resulted in a butter free from tallowiness, while the butter made from cream stored at 40° F. was very tallowy.

Oxidation-reduction studies showed a normal tendency toward reduction in freshly drawn milk. Upon the introduction of copper the potential was found to move toward the side of oxidation. Incubation of the milk usually caused a rapid drop in potential. Yeast cells likewise caused a reduction in potential.

Eh values of cream showed much the same effect of metal and temperature variables as Eh values of milk.

It is evident that oxidation-reduction potentials are related to fat oxidation in dairy products. Bacteria and yeast result in a change of potential towards the reduction phase, which suggests that a removal of oxygen occurs thru the metabolism process of the organisms. This undoubtedly explains why milk of very good quality, from a bacterial standpoint, is more likely to become tallowy than is milk more highly contaminated. Winter milk, especially that from certified dairies and other careful producers, may be expected to become tallowy readily when contaminated with copper salts.

Conclusions

1. Incubation of milk contaminated with copper at 68-90° F. retards the development of tallowiness which normally occurs in such milk stored at 40° F.

2. Incubation of milk at 68-90° F. previous to contamination with copper retards the development of tallowiness.

3. Growth of bacteria in milk will retard the development of tallowiness.

4. Yeast cells will retard the development of tallowiness in milk stored at 40° F.

5. Milks differ in their tendency to become tallowy.

6. Homogenization of milk contaminated with copper causes the tallowy flavor to be less apparent.

7. Incubation of cream contaminated with copper greatly reduces the degree of tallowiness in the butter. As much as 3.5 points difference in the score of butter may be effected by ripening metal-contaminated cream one or two days before churning.

8. Oxidation-reduction measurements on milk show that:
   a. Aseptically drawn milk will develop a lower Eh reading upon storage at either 40° F. or room temperature.
   b. The addition of a copper salt will cause the potential to rise rapidly toward the oxidation phase.
   c. Bacteria or yeast cells cause a rapid reduction to take place in the milk.

9. Oxidation-reduction measurements on cream show the same general effects of metal contamination and incubation as in the case of milk.

10. The metabolism of bacteria and yeast cells in dairy products plays an important part in the control of tallowy flavors. The effect is probably that of oxygen removal.

11. Bacterial metabolism in the raw milk probably accounts for the general absence of tallowy flavors in pasteurized milk produced during the summer months.

12. Lack of bacterial metabolism in raw milk probably accounts for the tendency for some pasteurized milk to become tallowy during the winter, especially in the case of those dairies that are able to control the quality of their milk from the time of production until it is placed in the bottle.

13. Lack of bacterial metabolism in the surplus sweet cream of milk plants and ice-cream plants during the winter months is probably the reason this cream, when churned, often produces a butter with a metallic, tallowy flavor.

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