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Butter

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1. INTRODUCTION

Buttermaking is one of the oldest forms of preserving the fat component of milk. Its manufacture dates back to some of the earliest historical records, and reference has been made to the use of butter in sacrificial worship, for medicinal and cosmetic purposes, and as a human food long before the Christian era. Documents indicate that, at least in the Old World, the taming and domestication of animals constituted the earliest beginnings of human civilization and culture. There is good reason to believe, therefore, that the milking of animals and the origin of buttermaking predate the beginning of organized and permanent recording of human activities.

The evolution of the art of buttermaking has been intimately associated with the development and use of equipment. With the close of the eighteenth century, the construction and use of creaming and buttermaking equipment (other than that made of wood) began to receive consideration, and the barrel churn made its appearance.

By the middle of the nineteenth century, attention was given to improvement in methods of creaming. These efforts gave birth to the deep-setting system. Up to that time, creaming was done by a method called shallow pan. The deep-setting system shortened the time for creaming and produced a better quality cream. An inventive Bavarian brewer, in 1864, conceived the idea of adapting the principle of the laboratory centrifuge. In 1877, a German engineer succeeded in designing a machine that, although primitive, was usable as a batch-type apparatus. In 1879,

Bailey's Industrial Oil and Fat Products, Sixth Edition, Six Volume Set.
Edited by Fereidoon Shahidi.

engineers in Sweden, Denmark, and Germany succeeded in the construction of cream separators for fully continuous operation (1).

In 1870, the year before the introduction of factory buttermaking, butter production in the United States totaled 514 million lbs, practically all farm made. Authentic records concerning the beginning of factory buttermaking are meager. It appears that the first butter factory was built in Iowa in 1871. This also introduced the pooling system of milk for creamery operation (1).

Other inventions that assisted in the development of the butter industry included the Babcock test (1890), which accurately determines the percentage of fat in milk and cream; the use of pasteurization to maintain milk and cream quality; the use of pure cultures of lactic acid bacteria; and refrigeration to help preserve cream quality.

Multiple butter fat products, including butter oils, anhydrous butter fat, butter fat–vegetable oil blends, and fractionated butter fats, are manufactured around the world today. In the past, butter fat in the form of butter was the primary preservation technique. Today, the preferred preservation method involves the processing of butter fat to the anhydrous butter oil state, then hermetically packaging under nitrogen to substantially increase the shelf life and reduce the incidence of degradation.

Historically, milkfat has been held in the highest esteem, whether in liquid milk, as cream, or as butter. Its consumption was associated with a higher standard of living. In recent times, with the prosperity of the Western world, per capita consumption has been decreasing. Ironically, this phenomenon contradicts all historical patterns for butter fat consumption and use. Several reasons exist for this decline. This chapter explores the chemical composition, marketing, technology, processing, quality, legal restrictions, and uses for butter and butter fat.

2. CHEMICAL COMPOSITION

Some of the information in this chapter comes directly from the fourth edition of Bailey's (2). Jensen and Clark (3) have provided a complete review of the lipid composition, and data have been selected for inclusion in this review.

The composition of milkfat is somewhat complex. Although dominated by triglycerides, which constitute some 98% of milkfat (with small amounts of diglycerides, monoglycerides, and free fatty acids), various other lipid classes are also present in measurable amounts. It is estimated that about 500 separate fatty acids have been detected in milk lipids; it is probable that additional fatty acids remain to be identified. Of these, about 20 are major components; the remainder are minor and occur in small or trace quantities (4, 5). The other components include phospholipids, cerebrosides, and sterols (cholesterol and cholesterol esters). Small amounts of fat-soluble vitamins (mainly A, D, and E), antioxidants (tocopherol), pigments (carotene), and flavor components (lactones, aldehydes, and ketones) are also present.

The composition of the lipids of whole bovine milk is given in Table 1 (4, 5). The structure and composition of the typical milkfat globule is exceedingly

TABLE 1. Composition of Lipids in Whole Bovine Milk (4, 5).

Lipid	Weight Percent
Hydrocarbons	Trace
Sterol esters	Trace
Triglycerides	97–98
Diglycerides	0.28–0.59
Monoglycerides	0.016–0.038
Free fatty acids	0.10–0.44
Free sterols	0.22–0.41
Phospholipids	0.2–1.0

complex. The globule is probably 2–3 μ in diameter with a 90-Å-thick membrane surrounding a 98–99% triglyceride core. The composition of the milkfat membrane is quite different from milkfat itself in that approximately 60% triglycerides are present, much less than in the parent milkfat (Table 2) (6, 7).

It has been generally recognized that butter fat consists of about 15 major fatty acids, with perhaps 12 or so minor (trace quantity) acids. Triglycerides are normally defined with respect to their carbon number (CN), i.e., the number of fatty acid carbon atoms present in the molecule; the three carbon atoms of the glycerol moiety are ignored. As the fatty acid spectrum of milkfat is dominated by acids containing an even number of carbon atoms, so is the triglyceride spectrum. However, the proportion of triglycerides with an odd carbon number is about three times greater than the proportion of odd-numbered fatty acids.

Although obvious correlations exist between fatty acid composition and triglyceride distribution, detailed information is lacking that would enable the triglyceride distribution to be predicted from the fatty acid composition. Much more needs to be understood of the strategy used in the bovine mammary gland in assembling a

TABLE 2. Composition of Lipids from Milkfat Globule Membrane (6, 7).

Lipid Component	Percent of Membrane Lipids
Carotenoids (pigment)	0.45
Squalene	0.61
Cholesterol esters	0.79
Triglycerides	53.4
Free fatty acids	6.3[a]
Cholesterol	5.2
Diglycerides	8.1
Monoglycerides	4.7
Phospholipids	20.4

[a]Contained some triglycerides.

TABLE 3. Characteristics and Composition of Butter Fats.

Characteristic	Value[a]	Range of Values[b]	GLC[c]
Iodine number	32.9	—	—
Saponification equivalent	236.3	—	—
Reichert-Meissle value	32.5	—	—
Polenske value	—	—	—
Kirschner value	—	—	—
Fatty acid, wt. %			
Butyric	3.5	2.8–4.0	3
Caproic	1.4	1.4–3.0	1
Caprylic	1.7	0.5–1.7	1
Capric	2.6	1.7–3.2	3
Lauric	4.5	2.2–4.5	4
Myristic	14.6	5.4–14.6	12
Palmitic	30.2	26–41	29
Stearic	10.5	6.1–11.2	11
Above C18	1.6	—	2
Total saturated	70.6	—	66
Decenoic	0.3	0.1–0.3	—
Dodecenoic	0.2	0.1–0.6	—
Tetradecenoic	1.5	0.6–1.6	2
Hexadecenoic	5.7	2.8–5.7	4
Octadecenoic (oleic, etc.)	18.7	18.7–33.4	25
Octadecdienoic	2.1	0.9–3.7	2
C20 and C22 unsaturated	0.9	—	1
Total unsaturated	29.4	—	34

[a] From (8) and (9).
[b] From (10) and (11).
[c] From (12).

complex array of fatty acids into triglycerides. This is not an arcane study; it is necessary if processes such as fractionation are to yield products with consistent qualities throughout the year. In effect, the detailed structure of milkfat is not yet understood. Perhaps this is not surprising if we consider only the 15 major fatty acids; there are 15^3 (3375) possible triglyceride structures using a purely random model.

The data in Table 3 represent general characteristics and composition of butter fat as reported by several sources (8–12). Note the range in values. Precise and repeatable values are not highly correlated due to such variables as stage of lactation, feed source, cattle breed, etc. Although 16 categories of fatty acids are outlined, it was generally appreciated that many other fatty acids are present in small or trace quantities. For nutritional and dairy science purposes, these data are of value, but from a detailed scientific point of view, they afford only a vague, broad generalization of the actual state of fatty acid composition of butter fat. A more complete view of composition is provided in Table 4 (13, 14).

From 1956 to 1983 a great volume of information became available on the occurrence of many minor constituents in butter fat. Somewhat less intensity

TABLE 4. Fatty Acid Composition of Milk and Butter Fat.[a]

Fatty Acid[b]	June[c]	December[d]	Average[e]	Moore and Co-workers[f]
4:0	4.22	3.51	3.57	3.98
6:0	2.53	2.24	2.22	2.36
8:0	2.34	1.07	1.17	1.36
9:0	0.05	0.05	0.03	—
10:0	2.24	2.57	2.54	2.76
10:1	0.32	—	—	—
11:0	0.34	0.29	0.33	—
12:0	2.40	2.77	2.81	3.14
13:0 (12:1)	0.29	0.29	0.33	0.14
14 (br)[g]	0.23	0.14	0.17	0.12
14:0	9.01	10.58	10.06	8.39
14:1 (15 br)	1.54	1.61	1.63	1.84
15:0	1.29	1.11	1.09	1.34
16 (br)	0.42	0.39	0.38	0.35
16:0	22.05	25.98	24.97	30.05
16:1 (17 br)	2.29	2.98	2.55	2.80
17:0	0.69	1.08	0.91	1.00
17:1 (18 br)	—	—	—	0.37
18:0 (br)	0.31	0.40	0.38	—
18:0	14.27	11.58	12.07	11.74
18:1	30.41	24.75	27.09	24.93
18:8[h]	0.24	1.56	1.26	—
18:2	1.23	2.75	2.39	1.78
18:3 (20:0)	2.61	2.30	2.06	1.23

[a] In weight percent.
[b] Structural assignments are not necessarily authentic, but represent, in almost all instances, the most likely structure for the fraction.
[c] Data from the Department of Animal Industries, Storrs (Conn.) Agricultural Experiment Station; 408 samples of milk plant production from June 1960 to June 1961.
[d] Data from Storrs Agriculture Experiment Station; 4–8 samples.
[e] For 108 samples.
[f] Sec (14).
[g] Branched chain.
[h] Carbon number obtained by semilog plots retention time/chain length.

of interest has prevailed since then, but further information continues to appear, and we can expect more data on butter fat as a consequence of research on the relationship between dairy cow feeding studies and resulting butter fat fatty acid composition.

The great variety of fatty acids in butter fat cannot be treated in detail here; reference will be made to only a few of the many available reports. Octadecadienoic acids are present in significant amounts; there are traces of hexadecadienoic acid, octadecatrienoic acids, and highly unsaturated C20 and C22 acids. Traces of dihydroxystearic acid and hydroxypalmitic acid have been detected (8, 9). A small proportion of the octadecenoic acid consists, not of oleic acid, but of *trans*-11,12 isomer, vaccenic acid (8, 9). One report states that about 66% of one octadecienoic

TABLE 5. Positional and Geometric Isomers of Bovine Milk Lipid Fatty Acids (wt. %) (16).

Position of Double Bond	*Cis*-Isomers				*Trans*-Isomers	
	14:1	16:1	17:1	18:1	16:1	18:1
5	1.0	Trace	—	—	2.2	—
6	0.8	1.3	3.4	—	7.8	1.0
7	0.9	5.6	2.1	—	6.7	0.8
8	0.6	Trace	20.1	1.7	5.0	3.2
9	96.6	88.7	71.3	95.8	32.8	10.2
10	—	Trace	Trace	Trace	1.7	10.5
11	—	2.6	2.9	2.5	10.6	35.7
12	—	Trace	Trace	—	12.9	4.1
13	—	—	—	—	10.6	10.5
14	—	—	—	—	—	9.0
15	—	—	—	—	—	6.8
16	—	—	—	—	—	7.5

acid content is normal linoleic acid, and the remainder consists of the *cis*-9, *trans*-12 or the *trans*-9, *cis*-12 isomers (15); but other positional and geometric isomers are undoubtedly also present (4). The positional and geometric isomers of bovine milk lipid fatty acids are presented in Table 5 (16).

TABLE 6. Fatty Acid Distributions of 82 Acids in Butter Fat.[a]

Saturated[b]		Branched[c]		Monoenes	
Acid	Weight Percent	Acid	Weight Percent	Acid	Weight Percent
—	—	12:0 i	0.01	10:1	0.48
8:0	0.69	13:0 i	Trace	12:1	0.05
10:0	1.88	14:0 i	0.03	13:1	0.003
11:0	0.12	15:0 i	0.14	14:1	0.75
12:0	2.96	15:0 2	0.23	15:1	0.02
13:0	0.10	16:0 i	0.2	16:1	1.84
14:0	11.2	17:0 i	0.36	17:1	0.2
15:0	1.52	18:0 i	0.02	18:1	30.3
16:0	27.8	19:0 br	0.01	19:1	0.14
17:0	0.71	20:0 br	0.01	—	—
18:0	12.1	21:0 br	0.01	—	—
19:0	0.05	22:0 br	0.02	—	—
20:0	0.02	23:0 br	0.01	—	—
21:0	0.06	24:0 br	0.02	—	—
22:0	0.04	25:0 br	0.0004	—	—
23:0	0.01	26:0 br	0.0004	—	—
24:0	0.02	20:1	0.52	—	—
25:0	0.02	21:1	0.01	—	—
26:0	0.02	22:1	0.02	—	—
27:0	0.00004	23:1	0.05	—	—
28:0	0.00004	24:1	0.0008	—	—
—	—	25:1	0.0008	—	—
—	—	26:1	0.0008	—	—

TABLE 6. Fatty Acid Distributions of 82 Acids in Butter Fat.[a] *(Continued)*

Dienes		Polyenes		Multibranched[e]	
Acid	Weight Percent	Acid	Weight Percent	Acid	Weight Percent
14:2	0.04	18:3	1.03	16:0 br3	0.01
16:2	0.02	18:4	0.10	17:0 br3	0.01
18:2	2.22	20:3	0.05	18:0 br3	0.16
20:2	0.12	20:4	0.07	—	—
22:2	0.14	20:5	0.02	—	—
24:2	0.02	22:3	0.03	—	—
26:2	0.0004	22:4	0.04	—	—
—	—	22:5	0.02	—	—
19:0 br4[d]	0.02	—	—	—	—
20:0 br4	0.14	—	—	—	—
21:0 br4	0.02	—	—	—	—
22:0 br4	0.02	—	—	—	—
23:0 br4	0.01	—	—	—	—
24:0 br4	0.10	—	—	—	—
25:0 br4	0.10	—	—	—	—
26:0 br3	0.01	—	—	—	—
27:0 br4	0.04	—	—	—	—
28:0 br3	0.02	—	—	—	—
28:0 br4	0.12	—	—	—	—
28:0 br5	0.01	—	—	—	—

[a]Detected by urea fractionation and gas–liquid chromatography in 1965 (17).
[b]Acid below 8:0 were not determined (totally or partially lost during removal of solvent); also did not measure *trans*-isomers, conjugated dienes and trienes, and keloacids.
[c]*i*, iso; *br*, iso and/or anti-iso. Last number indicates number of methyl branches for multibranched acids.
[d]The number following *br* indicates the number of methyl branches for multibranched acids.
[e]Tentatively identified in appropriate urea fractions by semilogarithmic plots of GLC retention times.

Few compilations of the extensive fatty acid distributions in butter fat have been made since Iverson et al. (17) reported quantitative data on 82 fatty acids that were detected by means of urea fractionation and gas–liquid chromatography (GLC) (Table 6). Table 7 provides the fatty acid composition of bovine milk lipids.

The advent of new techniques of gas chromatography for monoglycerides, diglycerides, and triglycerides (18, 19) should assist markedly in the identification of the specific triglycerides of butter fat. It has already been possible to identify and quantitate about 168 molecular species of bovine milk serum triglycerides, excluding enantiomers. Nutter and Privett (20) employed liquid–liquid and argentation thin-layer chromatography (TLC) along with pancreatic lipase hydrolysis for this purpose. As a result of their high degree of saturation, ruminant milkfats do not lend themselves readily to argentation TLC, and resolution by gas chromatography using polyester columns is a likely recourse.

There is a pronounced seasonal change in the fatty acid composition of butter fat. It is normally several iodine number units higher in the summer than in the winter, with corresponding variation in the relative proportions of unsaturated

TABLE 7. Fatty Acid Composition of Bovine Milk Lipids, August 1983 (3).

Number	Type	Identity
27	Normal saturate	2–28
25	Monobranched saturate	24; 13, 15, 17, 18 three or more positional isomers
16	Multibranched	16–28
62	Cis monoene	10–26, except for 11 : 1, positional isomers of 12 : 1, 14 : 1, 16 : 1–18 : 1, and 23 : 1–25 : 1
58	Trans monoene	12–14,16–24; positional isomers of 14 : 1, 16 : 1–18 : 1, and 23 : 1–25 : 1
45	Diene	14–26 evens only; cis, cis; cis, trans; or trans, cis and trans; trans, geometric isomers; unconjugated and conjugated and positional isomers
10	Tripolyene	18, 20, 22; geometric positional, conjugated and unconjugated isomers
5	Tetrapolyene	18, 20, 22; positional isomers
2	Pentapolyene	20, 22
1	Hexapolyene	22
38	Keto (oxo) saturated	10, 12, 14, 15–20, 22, 24; positional isomers
21	Keto (oxo) unsaturated	14, 16, 18; positional isomers of carbonyl and double bond
16	Hydroxy, 2-position	14 : 0, 16 : 0–26 : 0, 16 : 1, 18 : 1, 21 : 1, 24 : 1, 25 : 1
	Hydroxy, 4- and 5-position	10 : 0–16 : 0, 12 : △–6 and 12 : 1–△–9
60	Other positions	
1	Cyclic, hexyl	11; terminal cyclohexyl

and saturated fatty acids. In colder climates, the difference appears to be slightly larger. The change is usually associated with the difference in the feed of the animals in different seasons, but not completely so: cows put on green pasturage produce softer butter fat even if their feed has previously consisted of hay or silage comparable in solid composition with the green feed.

There are also differences in the butter fat of different cows on identical rations, and the age of the animal and duration of lactation have some influence on butter fat composition. Much of the dairy literature provides information relating dairy animal species and the composition of the butter fat from them.

When corn and peanut oils are protected (entrapped in formaldehyde-treated casein), significant changes in the fatty acid composition of milkfat occur (Table 8) (21).

Protected oils are hydrolyzed in the abomasum, and the fatty acids are absorbed in the small intestine, thereby avoiding hydrogenation. The 18:2 content in the milkfat was increased about five-fold, and the 14:0, 16:0, and 18:0 were decreased accordingly. Plasma and depot fats were also increased in 18:2 content by this program (21).

Results at the USDA are similar: cow's milk can be increased in 18:2 acid from 3% to 35% by feeding protected safflower oil (22, 23). However, at high 18:2 levels,

TABLE 8. Effect of Feeding Protected Corn and Peanut Oils on Fatty Acid Composition of Bovine Milkfat (4, 21).

	Fatty Acid Composition of Milk Lipids (wt. %)		
Fatty Acids	Corn Oil	Peanut Oil	Control
14 : 0	7.9	9.7	11.9
16 : 0	20.5	22.1	31.1
18 : 0	9.8	11.0	13.5
18 : 1	28.8	25.3	29.5
18 : 2	20.1	20.5	4.2
18 : 3	1.8	2.9	2.7
Others	11.1	8.5	7.1

milk develops an oxidized off-flavor, usually after about 24 h, and creams require a longer aging time for satisfactory churning. As expected, butter that contains more than 16% linoleic acid is soft and sticky (5).

Extensive data have been published on the Reichert-Meissl, Polenske, and Kirschner values of mixtures of butter fat, coconut, and palm kernel oils (Table 9) (24–26). Other average characteristics of butter fat are approximately as follows: density at 60°C, 0.887; melting point, 38°C; titer, 34°C; and unsaponifiable matter, 0.4%. The optical properties of butter fat are misleading and are in part contributed by the nonglyceride components.

A significant variation in milkfat composition can occur in colostrum milk. Ahren et al. (27) analyzed the content of glycerol ethers in neutral lipids and phospholipids isolated from bovine colostrum and milk (Table 10). Lactone content of butter fat has also been determined (Table 11).

Odd-numbered methyl ketones containing from 3 to 15 carbon atoms are found in small quantities in butter fat. These compounds, along with microtraces of acetone, acetaldehyde, methyl sulfide, C4–C10 free fatty acids, and the various lactones already mentioned, generally are considered to be the substances that comprise the pleasant, bland, olfactory, nonoxidative flavor and odor of milkfat. Representative concentrations of homologous methyl ketones have been well documented (30–32).

TABLE 9. Distinctive Characteristics of Butter Fat Compared with Other Fats (23).

Characteristic	Butter Fat	Coconut Oil	Palm Kernel Oil	Soy and Corn Fats and Oils
Saponification number	210–250	245–260	240–250	~200
Refractive index, 60°C	~1.4465	~1.4410	~1.4430	>1.4465[a]
Reichert-Meissl value	22.34	6.8	5.7	<1
Polenske value	2–24	14–18	10–12	<1
Kirschner value	20–26	1–2	0.5–1	<0.5

[a]Unless the iodine number is very nearly zero.

TABLE 10. Content of Glycerol Ethers in Neutral Lipids and Phospholipids Isolated from Bovine Colostrum and Milk (27).

Characteristic	Colostrum (% wt/wt)	Milk (% wt/wt)
Total lipids	5.6	3.9
Neutral lipids in total lipids	99.0	99.3
Phospholipids in total lipids	1.0	0.7
Glycerol ethers in total lipids	0.061	0.009
Glycerol ethers in natural lipids	0.06	0.007
Glycerol ethers in phospholipids	0.16	0.25
Glycerol ethers in natural lipids of total glycerol ethers	97.4	80
Glycerol ethers in phospholipids of total glycerol ethers	2.6	20

The phospholipids of milkfat are found in the fat globule membrane in association with proteins and cerebrosides. Phospholipids are amphipolar in nature and are strongly surface active. These properties enable them to stabilize both oil-in-water and water-in-oil emulsions (Table 12) (4–6).

The sterols found in the unsaponifiable fraction of milk lipids are mostly cholesterol esters, small quantities of lanosterol, and even smaller quantities of two new constituents: dihydrolanosterol and β-sitosterol (33).

From the standpoint of nutritional value, the Vitamin A content of butter is important. As the source of Vitamin A in butter is β-carotene or other carotenoid pigments in the feed of the cows, the content of this vitamin varies considerably, being highest in the summer when the dairy herds are in pasture and lowest in winter when there are no green feedstuffs in their rations. A portion of the carotene

TABLE 11. Amounts of y- and s-Aliphatic Lactones Isolated from Butter Fat (ppm) (2, 28, 29).

Carbon Number	*s*-Lactones	*y*-Lactones
6	2.0	Trace
7	0.2[a]	—
8	2.6	0.5
9	0.4[a]	0.2
10	15.0	1.2
11	0.7	0.5
12	35.0	1.6
13	1.5	0.5
14	34.0	1.4
15	6.4	1.3
16	23.2	1.3
18	2.3	—
2,3-Dimethyl-2,4-nonadien-4-olide	—	0.5

[a]Semiquantitative.

TABLE 12. Phospholipid Content of Bovine Milk (4–6).

Phospholipid	Mole Percent
Phosphatidylcholine	34.5
Phosphatidylethanolamine	31.8
Phosphatidylserine	3.1
Phosphatidylinositol	4.7
Sphingomyelin	25.2
Lysophosphatidylcholine	Trace
Lysophosphatidylethanolamine	Trace
Total choline phospholipids	59.7
Plasmalogens	3
Diphosphatidyl glycerol	Trace
Ceramides	Trace
Cerebrosides	Trace

in the feed is transferred to the butter fat without change. The amount of carotene transferred by the cow into the butter fat varies with the feeding regimen parallel to variations in the production of Vitamin A, so that the intensity of the yellow color of butter, to some extent, serves to indicate its Vitamin A content.

The Vitamin A potency of butter is in part due to Vitamin A as such and in part to carotene, which is partially converted to the vitamin in the human body. The Vitamin A content of butter is usually within the range of 6–12 mg/g, and the carotene content is in the range of 2–10 mg/g (33); 1 IU of Vitamin A is defined as the amount possessing the biological activity of 0.6 μg of pure β-carotene.

The Vitamin D content of butter is much less significant than that of Vitamin A, but it is nevertheless appreciable. It varies from about 0.1 IU/g to 1.0 IU/g, being highest in the summer and lowest in the winter (33).

The composition of milkfat is the most important factor affecting the firmness of butter and, therefore, its spreadability. The composition of milkfat changes primarily according to the feed; therefore, the entire problem is connected to the animal's diet. The fatty acid composition of milkfat produced in various countries has been rather accurately determined, as have the seasonal variations. In Europe, the amount of saturated fatty acids is generally highest in winter and lowest in summer or fall (see Table 11) (34). Green fodder decreases the amount of saturated fatty acids and correspondingly increases the amount of unsaturated fatty acids. The differences between the maximum and minimum values can be fairly large. For palmitic and oleic acids, the quantitatively most important fatty acids, a difference of more than 10% between the maximum and minimum values was found in some cases. This makes it understandable that there are also significant differences in the physical characteristics of the butter. The structure of the triglycerides in the milkfat, along with the fatty acid composition, is important in determining the physical characteristics of the fat, because the softening point of fat has been found to rise as the result of interesterification (35).

TABLE 13. Compositional Characteristics of Summer and Winter Milkfat (36).[a]

Samples	Fatty Acids				Iodine Number
	Volatile	Saturated	Monounsaturated	Polyunsaturated	
Average of total	10.98	56.50	29.81	2.50	32.2
Summer	9.49	58.82	33.53	3.14	36.8
Winter	12.45	59.15	26.15	1.86	27.7

[a] $N = 140$.

Textural characteristics of butter significantly depend on milkfat composition and the method of manufacture. If the chemical composition of the milkfat is known, it is possible to select the appropriate technological parameters of the buttermaking to improve its texture. To obtain butter with constant rheological characteristics and to control the parameters of the buttermaking process, it is necessary to take into account the difference in the chemical composition and the properties of the milkfat in various seasons. Table 13 shows various compositional changes of milkfat derived from summer and winter milk (36).

3. MODIFICATION OF MILKFAT

3.1. Melting and Crystallization of Milkfat Triglycerides

The complex fatty acid composition of milkfat is reflected in its melting behavior. Melting begins at $-30°C$ and is complete only at $37°C$. At any intermediate temperature, milkfat is a mixture of solid and liquid. To a large extent, the solid: liquid ratio determines the rheological properties of the fat. For example, at refrigeration temperature, butter has a higher solids content than does a tub margarine. Hence, the latter product is more easily spread (37).

As crystallization proceeds, the growing crystals impinge to form aggregates. A network results, in which both the solid and liquid phases may be regarded as continuous. Formation of the network greatly increases the firmness of the fat.

As a liquid fat is cooled, crystallization begins. There are two parts to the crystallization: (1) nucleation and (2) growth. In a bulk fat, nucleation occurs at the surfaces of impurities, a phenomenon described as heterogeneous nucleation. A considerable degree of supercooling is necessary to initiate nucleation. Subsequent growth of the nuclei tends to be slow in natural fats because of competitive inhibition. In materials of low molecular weight, impurities are rejected at the face of the growing crystal. In fats, however, the various triglyceride species are so closely related that the term *impurity* tends to lose its meaning (38).

3.2. Hydrogenation

Hydrogenation of various fats and oils is used extensively in industry but is not generally applied to butter fat (the high cost of the raw material argues against its use as

a feedstock). The process reduces the degree of unsaturation of the fat and increases its melting point.

Given the criticism directed at milkfat because of its saturated nature, there appears to be little future in increasing the degree of saturation by means of hydrogenation. The reverse procedure, desaturation or dehydrogenation, offers more attractive prospects.

Flavor deterioration in fat-rich milk and dairy products is mainly due to autoxidative degradation of lipids. This degradation may be retarded by partial hydrogenation. The objective of partial hydrogenation or trace hydrogenation is a selective saturation of the polyunsaturated fatty acids without saturation of the monounsaturated fatty acids to improve the oxidative stability. Selective hydrogenation has been studied for years in the vegetable oil industry with some success. This process has been applied by some researchers to milkfat (Figure 1) (39).

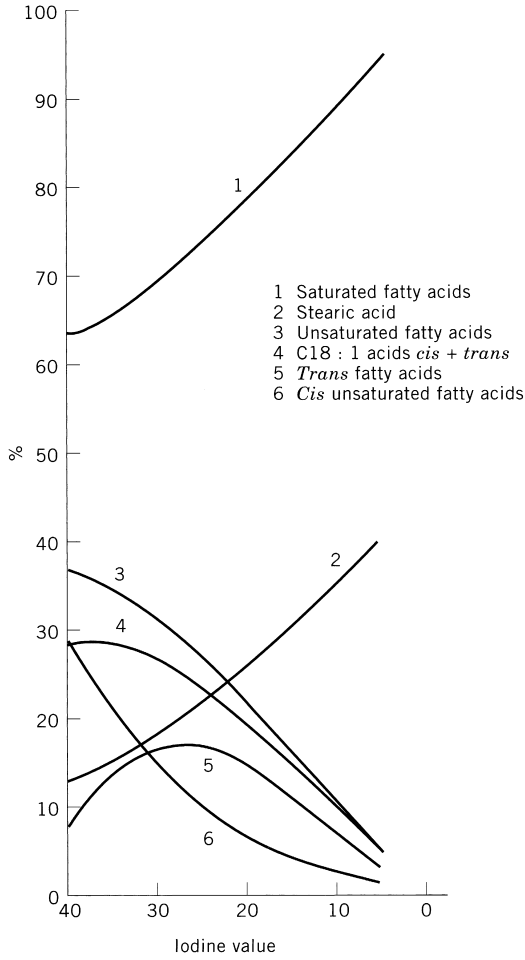

Figure 1. *Changes in the composition of fatty acids during the hydrogenation of milkfat (38).*

3.3. Interesterification

Interesterification (also called ester interchange, randomization, and *trans*-esterification) involves the exchange and redistribution of acyl groups among triglycerides. This technology was initially developed as high-temperature interesterification in Germany during 1920–1930. Since about 1950–1960, the process has been developed still further in the United States and Europe (39). The resultant product exhibits the same total fatty acid composition as the starting material, but the triglyceride composition and the physical properties are changed. Interesterification catalyzed by chemical catalysts or by lipases is used in the fat industry for the manufacture of margarines, shortenings, and confectionery fat (40).

The fatty acid composition is not modified by interesterification, but there is a significant modification of the glyceride composition (Table 14). In the untreated milkfat, the triglycerides may be divided into two groups: triglycerides with lower molecular weights (lower than C42) and the triglycerides with higher molecular weights (C44–C54) (39).

Interesterification offers opportunities for modifying the glyceride composition of milkfat and recombined butter. The technique confers some positive nutritive value to milkfat. One disadvantage of the interesterification reaction is the loss of flavor during neutralization, interesterification, and subsequent deodorization. Most manufacturers would support that little or no commercial interest will result from using this process.

TABLE 14. Glyceride Composition of Natural and Interesterified Milkfat (mol %) (39).

Triglyceride	Natural	Interesterified
C22	—	0.1
C24	0.3	0.8
C26	0.1	1.4
C28	0.6	1.5
C30	0.9	1.3
C32	1.9	2.0
C34	4.4	3.0
C36	9.5	5.9
C38	13.1	9.1
C40	12.1	9.9
C42	7.7	7.6
C44	6.8	8.3
C46	7.5	10.7
C48	8.8	12.8
C50	11.2	14.2
C52	10.8	10.9
C54	4.6	0.4
Ratio C38:C50	1.17	0.64

3.4. Reduction of Cholesterol in Milkfat

One obvious area for development is in the modification of dairy products to satisfy the changing dietary habits of consumers. The mounting health concerns are related to intake of calories, cholesterol, and saturated fats. Concern about cholesterol in the diet originates from the fact that high-serum cholesterol, especially the low-density lipoproteins, is one of the risk factors associated with atherosclerosis. Dietary intake of cholesterol may be one of the factors contributing to the elevation of serum cholesterol; other dietary factors are high total fat, high saturated fat, and low dietary fiber intake.

There have been many cholesterol-reduction technologies developed all over the world because of high interest by the dairy industry. However, there are only a few technologies available for technology transfer. Fractionation by thermal crystallization, steam stripping, short-path molecular distillation, supercritical fluid extraction, selective absorption, and crystallization using solvents or enzymatic modification can achieve fat alterations of significance to the dairy industry.

Vacuum Steam Distillation. There has been direct application of cholesterol removal by vacuum steam distillation, an old technology. This process is widely used in the fats and oils industry for deodorization.

Cholesterol is a low-volatile compound, but it is more volatile than the major triglycerides of milkfat. Superheated steam can be bubbled through the oil, heating it indirectly, which provides for the latent heat of vaporization of the distilling compounds and prevents steam condensation. Thus, the temperature and pressure can be varied independently. When the sum of the partial vapor pressures of water vapor and the distillates is equal to the total pressure, water vapor and the low-volatile components, such as cholesterol and free fatty acids, distill over.

The process for cholesterol removal from anhydrous milkfat was patented by General Mills (41). Fractionment Tirtiaux also disclosed the development of a vacuum steam distillation system called the LAN cylinder (38). The steam distillation process (Figure 2) was commercialized, producing a 90–95% cholesterol reduction in anhydrous milkfat with a 95% yield that was reconstituted into 2% fat fluid milk (42). The major disadvantage to the process is that it strips or removes most all volatile flavor components from the fat. These flavor components must be captured (i.e., vacreation) before the distillation process to attempt to reproduce the delicate flavors so desired for reconstitution into a butter product.

Short-path Molecular Distillation. Short-path molecular distillation offered great promise for the selective removal of cholesterol from milkfat. The process achieves the simplest separation of desired substance from a mixture of components of high molecular weight.

The rate of distillation at any given temperature is a function of the ratio $P{:}M^{1/2}$, where P is the partial pressure of the compound and M its molecular weight. Owing to the temperature dependence of the rate of distillation, a fractionation of components with different molecular weights can be carried out by holding the temperature constant until the more volatile constituents are removed. Figure 3 illustrates potential capability of the process (43).

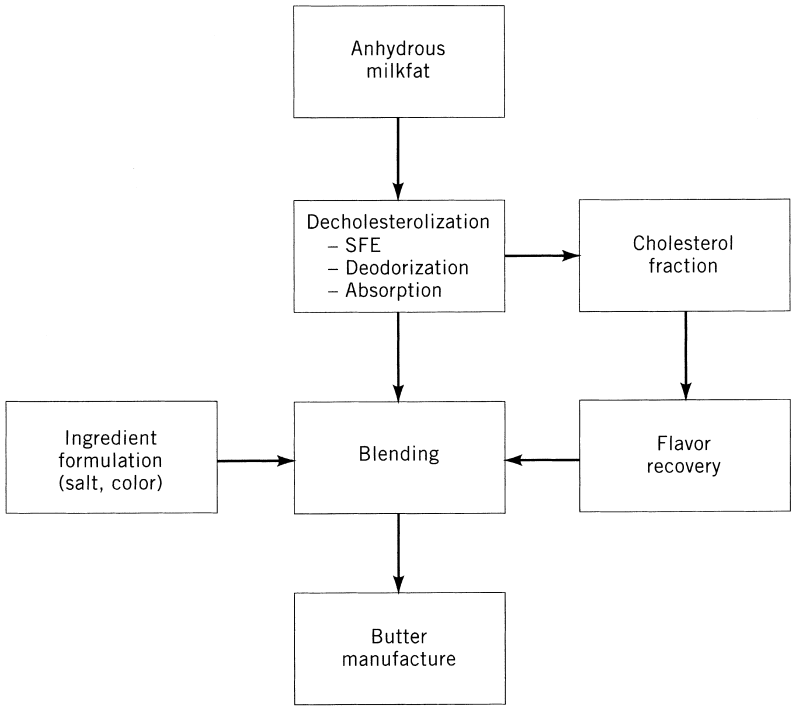

Figure 2. *Schematic for the decholesterolization of milkfat (41).*

The process has been applied to strip oil-soluble vitamins, sterols, and fatty acids from fats and oils. Cholesterol has been successfully removed from anhydrous milkfat in the range of 70–90% (44, 45). Extensive studies were performed and various temperatures and pressures were used to fractionate milkfat (46). Unfortunately, the process has not proved to be economically feasible due to the low butter fat yield when significant cholesterol was removed (Land O'Lakes research).

Absorption. One of the most promising technologies has been the use of cyclodextrins to complex cholesterol from a mixture and then selectively separate the cholesterol–cyclodextrin complex. European researchers have pioneered almost all of the research in this area, and patents have been issued (47, 48).

The process is based on the fact that β-cyclodextrin specifically forms an insoluble inclusion complex with cholesterol. β-Cyclodextrin is a cyclic oligosaccharide of seven glucose units. It consists of 1,4-*a*-D-linked glucopyranose residues, as shown in Figure 4. As a consequence of the C1 conformation of the glucopyranose units, the secondary OH groups are located on the edge of the torus-like cyclodextrin molecule, whereas all the primary OH groups are on the other side (Figure 5) (48). The central cavity is, therefore, hydrophobic, giving the molecule its affinity for nonpolar molecules such as cholesterol. The radius of the cavity can accommodate a cholesterol molecule almost exactly, explaining the highly specific nature of β-cyclodextrin's ability to form an inclusion complex with cholesterol.

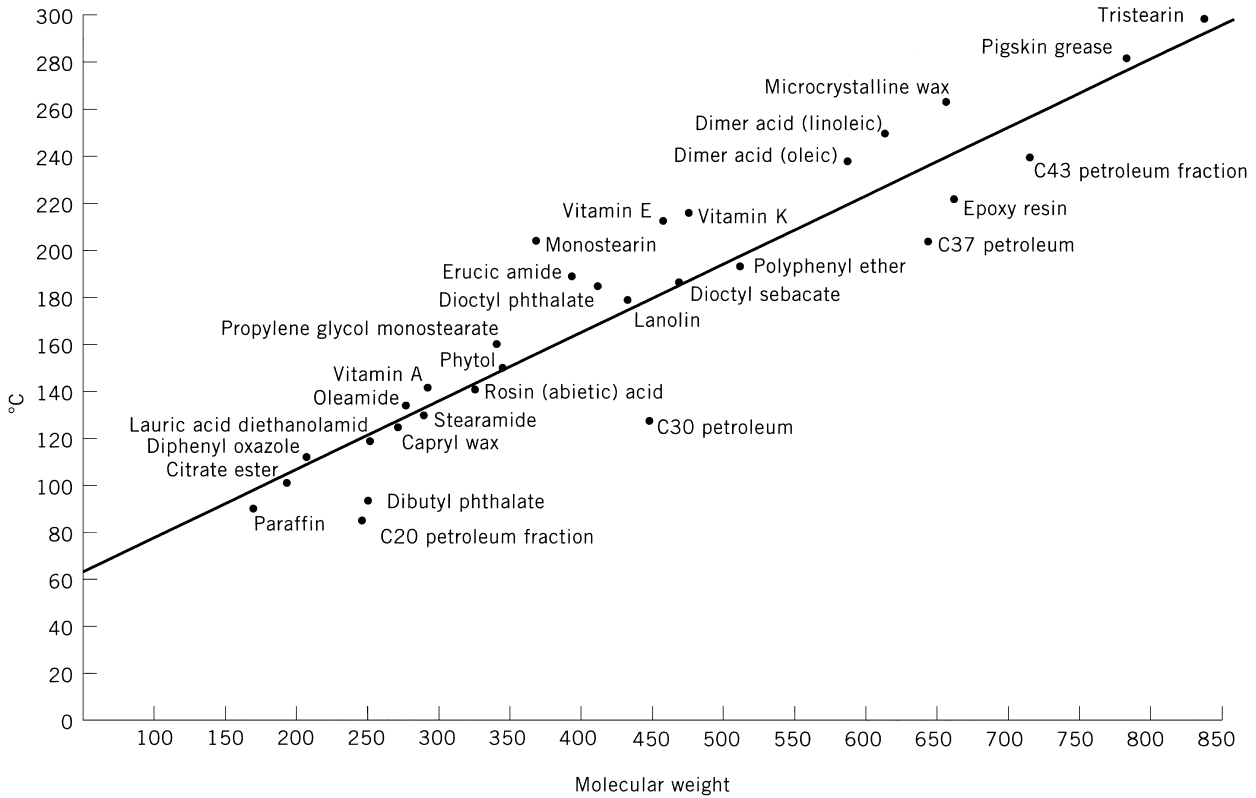

Figure 3. *Distillation under vacuum (43).*

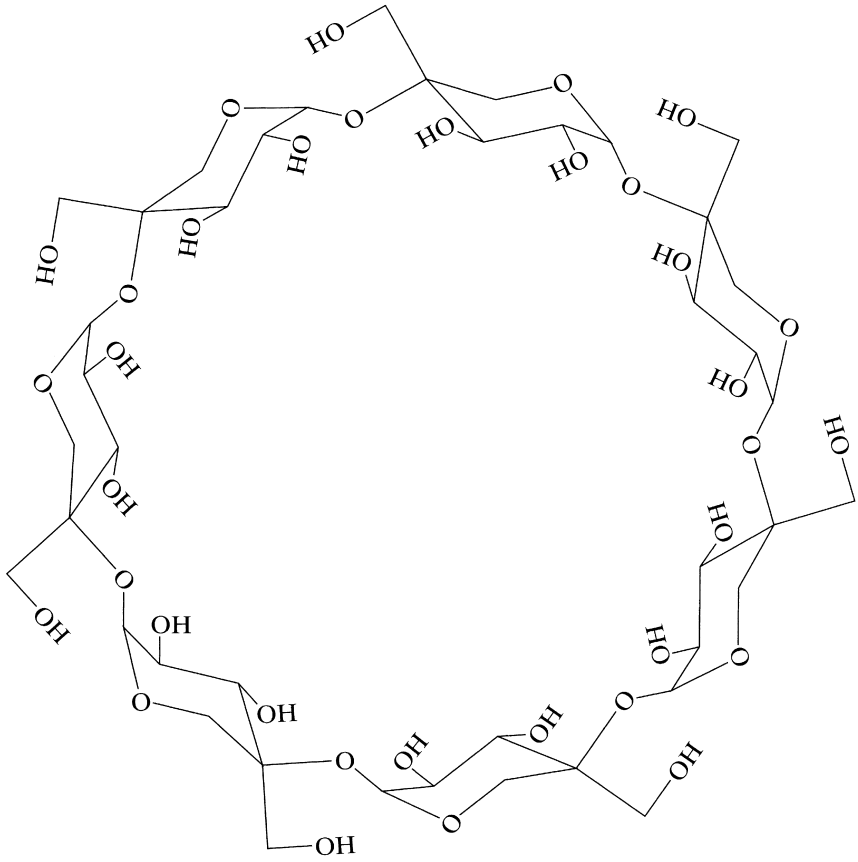

Figure 4. *β-Cyclodextrin*

This process appears to provide considerable economic and practical advantages over alternative cholesterol reduction technologies, such as steam distillation and supercritical carbon dioxide fluid extraction. For instance, there is no absorption of vitamins, it is a low-temperature operation, and it has a low capital cost. The only economic concern is that the ratio of the addition of β-cyclodextrin to the cholesterol removed is high, creating the potential for a high-cost process. Even so, the Europeans have commercialized the process, and reduced-cholesterol butter and cheese products have been introduced into the marketplace (49).

Multiple absorbants have been researched, and they include digitonin, tomatine, sodium cholate (bile salts), and active carbon (45, 47, 50). Most will face severe food regulatory problems. New Zealand (48) performed extensive research on active carbon, carbon impregnated with different metal salts, and inert supports impregnated with selected organic compounds. This technique (active carbon) is

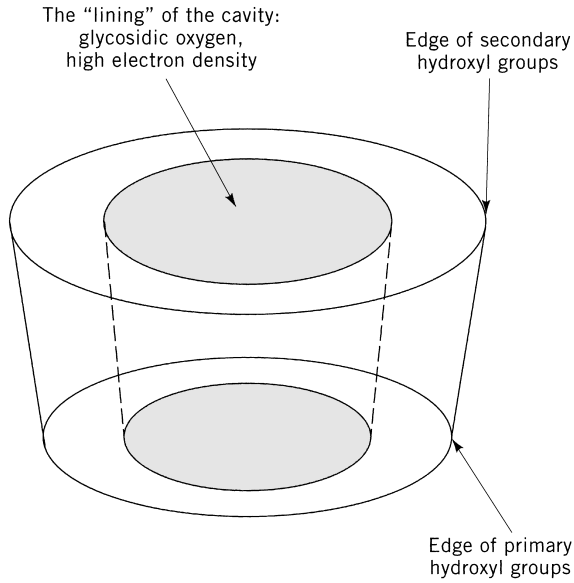

Figure 5. *Schematic of the β-cyclodextrin molecule, showing the hydrophobic cavity (48).*

not promising, because it does not retain the delicate butter flavors or the carotenoid pigments. An off-flavor develops in the milkfat. The University of California has evaluated the use of food-grade saponins as absorbents (51). This process showed promise, but most work has been discontinued due to U.S. regulatory prohibitions.

Solvents. The use of organic solvents, such as acetone, in the laboratory has proven to be an effective method for removal of milkfat components, including cholesterol. Unfortunately, this method creates regulatory and negative consumer perceptions due to the potential of solvent residues in the natural butter/butter fat-containing products.

Supercritical Fluid Extraction. The supercritical fluid extraction process created extensive excitement in the mid-1980s in the research community as a preferred process for cholesterol removal. Extensive research at various universities was initiated to evaluate its potential, and significant publicity was generated within the dairy industry (45, 46, 52–56).

Liquid-like densities of supercritical gases result in liquid-like solvent powers; this property and faster diffusion characteristics due to low-gas viscosity make supercritical fluids attractive extraction agents. Solubility of substances in supercritical gases derives from van der Waals' molecular attractive forces and increases with increasing pressure at a constant temperature. The temperature influences the solution equilibria in a more complicated way than does the pressure. Compounds can be selectively dissolved by changing the density of the gas, i.e., pressure and temperature conditions.

The extraction of cholesterol into the mobile gas phase is determined by the balance of a tripartite interaction: triglyceride–CO_2, triglyceride–cholesterol, and

cholesterol–CO_2. As a minor constituent of the milkfat, cholesterol is probably associated with the triglycerides for which it has higher affinity, namely, short- and medium-chain triglycerides and, to some extent, long-chain unsaturated triglyerides. As CO_2 affinity is low for cholesterol at 200 bar and 80°C (low-gas concentration), there would be less competition between triglycerides and CO_2 for cholesterol. Those cholesterol molecules associated with short- and medium-chain triglycerides would be eluted into the gas phase along with them at low-gas concentrations. However, the cholesterol molecules associated with long-chain triglycerides are not eluted at low-gas concentrations because of their larger size. Cholesterol esters, being large molecules, would not be eluted at low-gas concentrations.

By the late 1980s, technologies for the removal of cholesterol with supercritical carbon dioxide were offered by a number of companies (38). Commercialization was never attempted by any major food company for removal of cholesterol. Successful scale-up and commercialization was achieved by the General Foods Corporation for removal of caffeine from coffee (45). The primary disadvantages for the dairy industry were the low yields, low cholesterol removal, and the very high capital and operating costs of the equipment.

Enzymatic. Biological procedures for cholesterol removal make use of micro-organisms that produce enzymes to convert cholesterol into innocuous compounds. Several enzymatic systems are being investigated in different countries of the world. Most systems use a cholesterol reductase that converts the cholesterol into coprostanol and coprosterol (52, 57). These converted compounds are very poorly absorbed by the digestive system and pass through intact. Several investigators have isolated and characterized *Eubacteria* able to convert cholesterol into coprostanol from rat, baboon, and human feces. Leaves of cucumber, soybeans, corn, and beans are known to contain similar enzymes (45, 57, 58). *Lactobacillus acidophilus* has also been reported to metabolize cholesterol (51).

Once suitable enzyme systems are identified, the next step involves transfer of the gene that codes for the enzyme into suitable micro-organisms, such as *Lactobacillus* and *Streptomyces* species, for large-scale production and purification of the enzyme. Further steps may involve attaching the enzyme onto a solid support or adding purified enzyme in soluble form to the food systems. It is equally envisioned that cholesterol-degrading enzymes, such as cholesterol reductase, can be genetically transplanted from one group of bacteria into lactic bacteria, which are the traditional dairy starter cultures. The cholesterol-reducing cultures could then be used in cultured dairy products such as cheese.

The industrial scale-up of enzymatic technology is both highly complicated and expensive. Moreover, a primary regulatory hurdle will involve demonstrating that the end products of the cholesterol–enzyme reaction and the novel compounds formed through genetic engineering are harmless.

Regulatory–Nutritional. Many of the processes for cholesterol removal will meet with regulatory hurdles because of residues, unapproved additives, or byproduct formation. But the real burden for the U.S. dairy industry was the 1993 Nutritional Labeling and Education Act (54). This act created commercial prohibitions,

because it requires that cholesterol-reduction claims cannot be applied to products that contain more than 2 mg/g of saturated fat; butter fat is approximately 65% saturated. The industry has not yet developed a cost-effective means to reduce butter fat saturation.

For years, the nutritional community has claimed that the effect of dietary cholesterol intake on serum cholesterol level was much less significant than the ratio of total fat to saturated fat in the diet (59). The general public is becoming aware of this and has consequently reduced its demand for low-cholesterol foods.

4. QUALITY CONTROL

In the production of all butter-fat-containing foods, quality control is essential to ensure shelf life, safety, and the food's appearance, flavor, and texture. The key to the final product is the quality of the raw materials used. The handling of raw milk is of particular importance. Careful attention is paid to temperature control in raw-milk-handling systems and, naturally, to the cleaning of all equipment used for storage and transport. Raw milk is held refrigerated to less than 5°C on the farms, and although this has eliminated the growth of a number of organisms, others (notably psychrotrophs) can still multiply under these conditions. Unfortunately, some of the lipolytic and proteolytic enzymes produced by these classes of organisms are heat stable, even surviving ultrahigh temperature (UHT) treatment. Today, a shelf life of many months is expected of a number of UHT-treated products, thus the presence of lipolytic and proteolytic enzymes can be disastrous. The only way to avoid this problem is to ensure that the numbers of organisms are kept to an absolute minimum during all stages of the collection and manufacturing process.

Some quality problems can be eliminated. For example, certain cattle feeds produce undesirable volatile flavors, which tend to concentrate in the butter fat portion of the milk. Historically, the industry adopted steam stripping of cream for buttermaking to reduce the intensity of these flavors. The equipment universally used is the vacreator (Figure 6), which is designed to pass as much as 0.30 kg steam to each kilogram of cream. The design of the vacreator evolved during the 1930s and 1960s, culminating in the development of the Vac 25 and 16 models (59).

Vacreation accomplishes a number of tasks in one operation. Pasteurization of the cream for buttermaking is perhaps the most important of these, followed by steam stripping of off odors. Other functions include destruction of natural milk lipases and development of a slightly ''nutty'' or ''cooked'' flavor in the resulting butter.

4.1. Hazard Analysis and Critical Control Points (HACCP)

The World Health Organization (WHO) recognized HACCP as an effective rational means to ensure food safety from the farm to consumer. The Food and Drug Administration (FDA) and the U.S. Department of Agriculture (USDA) are moving

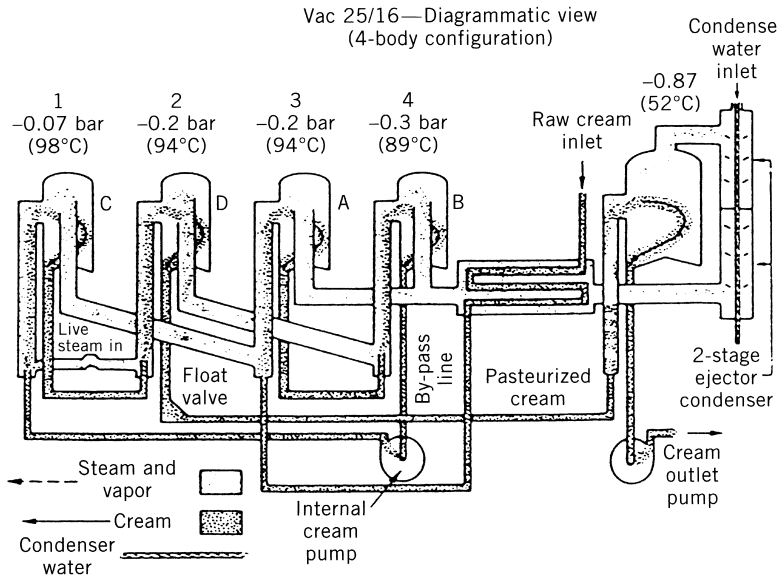

Figure 6. *Diagram of the Vac 25/16 vacreator (59).*

toward the adoption of HACCP systems to ensure the safety of foods sold in the United States.

The HACCP program is a management tool that provides a logical and cost-effective basis for better decision making with respect to dairy product safety. One of the key advantages of the HACCP concept is that it enables a dairy food manufacturing company to move away from a philosophy of control based on testing to a preventive approach that identifies and controls potential hazards in the manufacturing environment.

4.2. Composition Control

Composition control of the butter fat content has received much attention in the ever present drive to maximize returns and create highly consistent products. As noted, multiple technologies are under development to standardize and simplify the processes.

4.3. Grading, Standards, and Definition

Standards for butter in the United States were established by an act of Congress and are supported by USDA standards for grades of butter. In the revised standards, the following definitions apply: *butter* refers to the food product usually known as butter, which is made exclusively from milk, cream, or both, with or without common salt, and with or without additional coloring matter. The milkfat content of butter is not less than 80% by weight, allowing for all tolerances. *Cream* refers to the cream

separated from milk produced by healthy cows. Cream is pasteurized at a temperature of not less than 73.9°C for not less than 30 min, or it can be pasteurized at a temperature of not less than 89°C for not less than 15 s. There are other approved methods of pasteurization that give equivalent results (60).

The flavor of the cream may be enhanced by culturing, adding food-grade lactic acid bacteria, or adding natural flavors obtained by distilling a fermented milk; cream may also be added to the finished butter. In addition, color, derived from an FDA-approved source, may be used (61).

Legal requirements for butter vary considerably in different countries. For example, in Europe, butter must contain 82% fat, and in France, it may contain a maximum of 16% moisture (62). In some tropical parts of the world, milkfat is used in nearly anhydrous form, because it is less susceptible to bacterial spoilage. This product is known as ghee. In the Middle East and India, ghee is prepared from heated cow or buffalo milk.

The new nutrition labeling regulations, promulgated under the Nutrition Labeling and Education Act of 1993 (54), mandate that only strictly defined terms be used to make nutrient content claims. For example, the term *light* may only be used on products that have been specifically formulated or altered to meet one of two conditions: (1) if the product derives 50% or more of its calories from fat, reduce the fat level by 50% (as compared with a reference product), and (2) if the product derives less than 50% of its calories from fat, reduce the calorie level by one-third (compared with a reference product). Generally, butter products derive more than 50% of their calories from fat and, therefore, must achieve a minimum 50% fat reduction to use the term *light*. The term *reduced* when used as a nutrient descriptor requires a formulation alteration that achieves a minimum 25% reduction in the nutrient from a reference product (63).

When considering products to be labeled with a cholesterol claim, the following applies:

Reduced cholesterol: the product has an allowable maximum of 2 g saturated fat and a minimum 25% cholesterol reduction per serving.

Low cholesterol: maximum of 2 g saturated fat and a maximum of 20 mg cholesterol per serving are allowed.

Cholesterol free: maximum of 2 g saturated fat and less than 2 mg cholesterol are allowed per serving.

When considering a fat free or no fat claim, the new regulations require the product to have less than 0.5 g fat per serving and no added fat unless noted (i.e., ''trivial fat'') (54).

There are three U.S. grades of butter: AA, A, and B. Butter is graded by first classifying its flavor organoleptically. In addition to the overall quality of the butter flavor itself, the standards list 17 flavor defects and the degree to which they may be present for each grade. This grade is then lowered by defects in the workmanship and the degree to which they are apparent. Deratings are characterized by negative body, flavor, or salt attributes, which are fully described in the standards. Butter

TABLE 15. Standards for Anhydrous Milkfat, Anhydrous Butter Oil, and Butter Oil (65).[a]

Composition and Quality	Anhydrous Milk Fat	Anhydrous Butter Oil	Butter Oil
Milk fat, minimum	99.8% m/m	99.8% m/m	99.6% m/m
Water	0.1% m/m	0.1% m/m	0.3% m/m
Free fatty acids, as oleic acid, maximum	0.3% m/m	0.3% m/m	0.4% m/m
Peroxide value, m Eq oxygen/kg fat, maximum	0.3	0.3	0.6
Copper, mg/kg, maximum	0.05	0.05	0.05
Iron, mg/kg, maximum	0.2	0.2	0.2

[a]Taste and odor at 40–45°C should be acceptable for market requirements. Texture, depending on temperature, should be smooth and fine granules to liquid.

that does not meet the requirements for U.S. Grade B is not graded. To bear the USDA seal, the finished product must fall within the following microbiological specifications:

Proteolytic count not more than 100 per gram.
Yeast and mold count not more than 20 per gram.
Coliform count not more than 10 per gram.

Butter should be stored at 4.4°C or lower or at less than −17.8°C, if it is to be held for more than 30 days (62). The International Dairy Federation (IDF) has produced specifications for milkfat (64), which include reference to the feedstock. (These specifications relate to the time of manufacture but are often used as purchase standards.) The highest grade, anhydrous milkfat (AMF), must be produced from fresh milk, cream, or butter, to which no neutralizing substances have been added. It should have a clean, bland flavor when tasted at 20–25°C and a peroxide value (PV) of less than 0.2 meq oxygen/1 kg fat. Anhydrous butter oil may be produced from butter or cream of different ages and has no pronounced, unclean, or other objectionable taste or flavor. The term *butter oil* should be used where there is no pronounced unclean or other objectionable taste or odor. The FAO/WHO Codex standard for milkfat is shown in Table 15 (65).

4.4. Specialized Analytical Methods

The dairy industry produces a valuable fat that has a desirable flavor and positive consumer awareness; these attributes must be protected. Significant development activity has occurred for rapid, simple methods to detect adulteration (66, 67). As lack of spreadability was determined to be a major butter negative, a flurry of research was initiated creating the need for measurement techniques (68–70). Many procedures have been used or proposed to assess the microbiological quality of the milk or cream. Generally, microbiological tests are performed to determine the hygiene of production and storage conditions or for safety reasons. Tests include

total counts and counts for specific classes of micro-organisms, such as yeasts and molds, coliforms, psychotrophs, and pathogens such as *Salmonella*. Rapid-screening tests based on dye reduction or direct observation using a microscope or automatic total counters are also in use.

4.5. Lipase Activity

An increasing problem is lipolysis in butter fat after manufacturing, which is caused by thermoresistant lipase enzymes that are created in the milk or cream by psychotrophic bacteria or by residual native lipases that survive pasteurization. Based on a determination of the lipase activity in cream, the keeping quality of manufactured butter in regard to lipolysis can be predicted with reasonable accuracy. A similar prediction for sweet cream butter can be based on lipase activity in the serum phase (71). The characteristic lipolytic flavors that can develop in milk products are primarily associated with the short- and medium-chain fatty acids that are relatively abundant in milkfat; they have lower flavor threshold values than the long-chain fatty acids. As a result of improvements in the quality of raw milk and the standards of processing, lipolytic rancidity is seldom present in the fat source before its use in recombination (72).

4.6. Oxidation

The flavor of dairy products is largely determined by the fat component. Consequently, it is particularly important to restrict the development of oxidized off-flavors in the fat source before use. Oxidation is the chief mode of deterioration of fats and a major factor in determining the shelf life of fat-containing foods (72). Unsaturated fatty acid esters react with oxygen to form peroxides. Although flavorless themselves, peroxides are unstable and readily decompose to yield flavorful carbonyl compounds. The latter are the source of the characteristic oxidized flavors that are detectable at low concentrations. The rate of oxidation depends on the concentration of dissolved oxygen, the temperature, the presence of pro-oxidants such as copper and iron, the degree of unsaturation of the fat, and the presence of antioxidants that may retard the onset of oxidation. Compared with many fats, milkfat has a good oxidative stability, because it is high in total saturates, low in polyunsaturates, and contains natural antioxidants, principally α-tocopherol.

The development of oxidative rancidity in milkfat is the major determinant of the stability of the fat on storage. Dissolved air in the milkfat can give dissolved oxygen levels of up to 40 ppm at 30°C. In practice, the dissolved oxygen level in the freshly processed milkfat would be about 5 ppm at 45°C, a level sufficient to permit the development of oxidative rancidity, but if the milkfat were allowed to equilibrate with the air, then this level could increase to 33 ppm with a consequent increase in the rate of development of oxidative rancidity. The solubility curve for oxygen in milkfat is a compound of the solubility curves for the liquid and solid phases (Figure 7). Though the solubility decreases with increasing temperature for both phases, the solubility of oxygen in the liquid phase is much higher than for the closely packed solid phase (73).

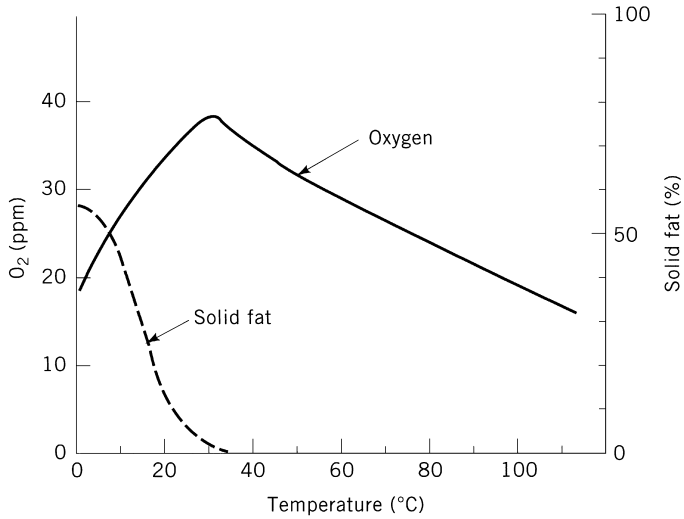

Figure 7. *The effect of temperature on the solid fat content and solubility of oxygen in milkfat (73).*

The oxygen level in the milkfat may be limited by either active or passive actions. For passive control, processing procedures and plant design are established to minimize air exposure. Deaeration devices (74), vacreation (60), the use of antioxidants (72), effective destruction of lipases (75), and nitrogen spanning of container headspace are examples of active control of product quality.

5. BUTTER MANUFACTURE

5.1. Milk and Cream Separation

The most basic and oldest processing method is cream separation. Ancient people are known to have used milk freely. It is probable that they used the cream that rose to the top of milk that had been held for some time in containers, although there is little in ancient literature to suggest that such use was common. It is well established that, in early times, butter was produced by churning milk.

The principal questions concerning separation in a butter manufacturing facility are the choice of cream fat content and the choice of the separation technique, milk separation before or after pasteurization, temperature of separation, and regulation of the fat content. Separation of cream from milk is possible because of a difference in specific gravity between the fat and the liquid portion, or serum. Whether separation is accomplished by gravity or centrifugal methods, the result depends on this difference (48).

A modern dairy separator will separate virtually all fat globules larger than 0.8 μm, and because most of the milkfat is present in the form of such globules,

it is relatively easy to separate the bulk of the milkfat. Fat globules below 0.8 μm are generally referred to as nonseparable globules (76).

The percentage of fat in the cream must be known and controlled. It influences fat losses during churning. Knowledge of the fat content assists in yield estimations for operational conditions in continuous manufacture. A number of satisfactory analytical procedures are available, with the Babcock test being the most common.

The chemical composition of the triglycerides, which make up milkfat, varies throughout the year, depending on the stage of lactation and the cow's diet. The seasonal variation causes a cyclic change in the melting properties of the fat. In the control of the buttermaking process and the physical properties of the finished butter, this factor must be monitored. The term *melting property* is used rather than softness or hardness, because these more correctly refer to altogether different attributes of solids. A number of procedures have been used to follow the seasonal change in the melting properties. The iodine number, refractive index, differential scanning calorimetry, or pulsed nuclear magnetic resonance spectroscopy can be used to prepare a melting curve. However, the expense and complexity of these melting curve techniques precludes this approach in most quality-control situations (77). The traditional chemical determinations for fat, saponification value, and Polenske value are of limited value. They are scarcely relevant for quality control, and the information they provide can be more usefully quantified by the determination of the fatty acid profile using gas chromatography.

Today, the use of stainless steel has essentially eliminated the exposure of the fat to copper and iron. The presence of copper and, to a lesser extent, iron can catalyze oxidative deterioration of butter during storage, particularly in the presence of salt and a low pH.

5.2. Crystallization

The crystal structure of fat and the resulting physical properties of butter made by both conventional and alternative processes have received considerable study. When churned conventionally or by the continuous Fritz process for butter manufacture, most of the milkfat is contained within the fat globule in cream during the cooling and crystallization process. The fat globule provides a natural limit to the growth of fat crystals. Cooling and holding of cream is normally carried out overnight, and thus, sufficient time exists for the crystallization process to approach equilibrium (78).

The principles of crystallization of plastic fats in the type of equipment used for margarine manufacture have been described (79). It is important for the butter to develop small fat crystals that remain substantially discrete and do not form a strong interlocking structure. Small crystals (e.g., 5 μm diameter) have a greater total surface area than large crystals and will bind water and free liquid fat by adsorption more effectively (78). Large crystals impart a gritty texture to the product. When fats are cooled rapidly in a scraped-surface heat exchanger, fat crystallization commences, but the fat is substantially supercooled on exiting. If

crystallization is then permitted to continue under quiescent conditions, crystals will grow together and form a lattice structure. The product will thus be hard and brittle and may tend to leak moisture. If, however, crystallization is permitted to occur under agitated conditions (e.g., for 1–3 min in a pin worker), the formation of small independent crystals will be favored and the product will have a fine, smooth texture. If crystallization under agitated conditions is permitted to continue for too long, the product will be too soft for most patting or bulk filling operations, and it is likely to be too soft and greasy at warm room temperatures.

5.3. Neutralization

When lactic acid has developed in the raw, unpasteurized cream by microbial activity to a degree considered excessive, neutralizer may be added to return the cream acidity to a desirable level. Sodium carbonates have been found suitable in practice for batch neutralization. For continuous neutralization by pH control, sodium hydroxide is more suitable. These chemicals must be food grade.

5.4. Heat Treatment

The heat treatment of cream plays a decisive role in the butter-manufacturing process and the eventual quality of the butter. It is important that milk and cream be handled in the gentlest possible way to avoid mechanical damage to the fat, a serious problem in continuous manufacture (Fritz process) of butter (80). Cream is pasteurized or heat treated for the following reasons: to destroy pathogenic micro-organisms and reduce the number of bacteria, to deactivate enzymes, to liquify the fat for subsequent control of crystallization, and to provide partial elimination of undesirable volatile flavors.

5.5. Batch Butter Manufacture

Today, batch processing is not used to any extent for the production of large quantities of butter. Batch systems are still encountered in small butter plants, primarily in less industrially developed countries. Continuous systems are more efficient and cost-effective for large outputs; batch systems have low capital cost.

The processing of cream by a batch churn requires filling to approximately 30–50% capacity at a cream temperature of 4.4–12.8°C. Cream temperature varies, depending on season, the butter characteristics desired, and the desired rate of fat inversion (Figure 8). Churning is accomplished by rotation of the churn at approximately 35 rpm until small butter granules appear. The process usually requires about 45 min for coalescence of the fat globules and clean separation of the buttermilk so that it can be drained (82). The granules may be washed with cold water to remove surface buttermilk. Salt is then added with water if standardization of the fat content is required. The butter is worked to ensure uniformity and desirable body and texture characteristics and the rate of fat inversion.

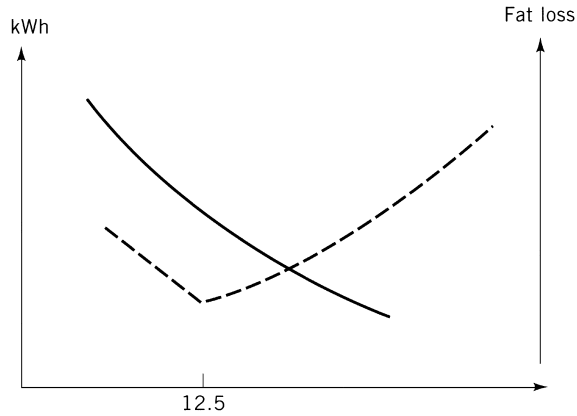

Figure 8. *Energy consumption and fat loss in buttermilk in relation to churning temperature and heating temperature (81).——, Energy consumption; ——, fat loss.*

5.6. Continuous Butter Manufacture

Between 1930 and 1960, a number of continuous processes were developed. In the Alfa, Alfa-Laval, New Way, and Meleshin processes, phase inversion takes place by cooling and mechanical treatment of the concentrated cream. In the Cherry-Burrell Gold'n Flow and Creamery Package processes, phase inversion takes place during or immediately after concentration, producing a liquid identical to melted butter, before cooling and working. The Alfa, Alfa-Laval, and New Way processes were unsuccessful commercially. The Meleshin process, however, was adopted successfully in the former U.S.S.R. The Cherry-Burrell Gold'n Flow process appears to have been the more successful of the two American processes (78).

The Fritz continuous buttermaking process, which is based on the same principles as traditional batch churning, is now the predominant process for butter manufacture in most butter-producing countries. In the churning process, crystallization of milkfat is carried out in the cream, with phase inversion and milkfat concentration taking place during the churning and draining steps. However, because of the discovery that cream could be concentrated to a fat content equal to or greater than that of butter, methods have been sought for converting the concentrated or plastic cream directly into butter. Such methods would carry out the principal buttermaking steps essentially in reverse order, with concentration of cream in a centrifugal separator, followed by a phase inversion, cooling, and crystallizing of the milkfat (82).

Increased demands on the keeping qualities of butter require careful construction, operation, and cleaning of the milk- and cream-processing equipment, as well as research to develop machines that will ensure butter production and packing under conditions without contamination and air admixture. It has been demonstrated that butter produced under closed conditions has a better keeping quality than butter produced in open systems (83).

There are two classes of continuous processes in use: one using 40% cream, such as the Fritz process (Figure 9) (81), and the other using 80% cream, such as the

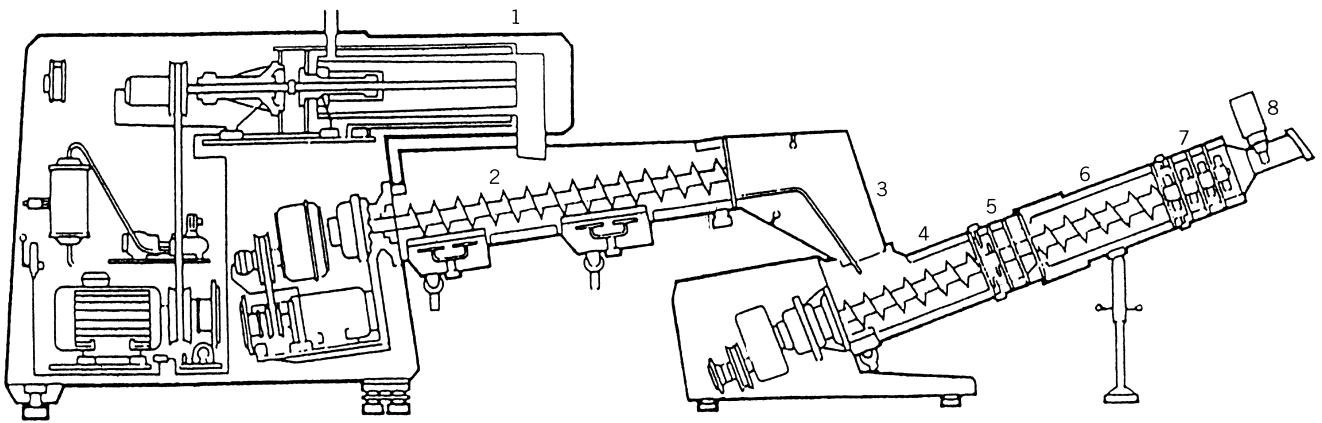

Figure 9. *Continuous butter maker (Westfalia). 1, Churning cylinder; 2, separation section (first working section); 3, squeeze-drying section; 4, second working section; 5, injection section; 6, vacuum working section; 7, final working stage; and 8, moisture-control unit (81).*

Cherry-Burrell Gold'n Flow (84). As much as 85% of the butter in France is made by the Fritz process. In this process, 40% fat cream is churned as it passes through a cylindrical beater, all in a matter of seconds. The butter granules are fed through an auger where the buttermilk is drained and the product is squeeze-dried to a low-moisture content. It then passes through a second working stage where brine and water are injected to standardize the moisture and salt content. As a result of the efficient draining of the buttermilk, this process is suitable for the addition of lactic acid bacteria cultures at this point. The process then becomes known as the NIZO method when the lactic starter is injected (78). Advantages of the NIZO method over traditional culturing are improved flavor development, improved acid values as a result of lower pH, more flexible temperature treatment of the cream because culturing and tempering often are accomplished concurrently, and most important, production of sweet cream buttermilk.

The Cherry-Burrell Gold'n Flow process is similar to margarine manufacture (84). The process starts with 18.3°C cream that is pumped through a high-speed destabilizing unit and then to a cream separator, from which a 90% fat plastic cream is discharged. It is then vacuum pasteurized and held in agitated tanks to which color, flavor, salt, and milk are added. Then this 80% fat-water emulsion, which is maintained at 48.9°C, is cooled to 4.4°C by use of scraped surface-heat exchangers. It then passes through a crystallizing tube and then a perforated plate that works the butter. Before chilling, 5% nitrogen gas is injected into the emulsion. Improvements of the processing continue to occur. It is now possible to manufacture butter from high-fat cream (>82% milkfat) on a continuous basis (85).

Although the Meleshin process continues to be in widespread use in the former U.S.S.R., the use of alternative continuous buttermaking processes based on high-fat cream has declined in Western countries during the past 20 years (78). The principal reasons for this decline appear to be economics and butter quality, particularly when compared with the Fritz process. A Fritz manufacturing process can be installed in existing batch churn factories with almost no modification to cream-handling or butter-packing equipment. The churns could be retained in case the Fritz breaks down. However, little batch plant equipment could be reused in the alternative systems (i.e., Gold'n Flow). When a completely new plant is being bought, the alternative systems still tend to be more expensive, and operational advantages over the Fritz system are not significant. Butter from the Fritz process is nearly identical in its physical and flavor characteristics to batch-churned butter, whereas butter produced by the alternative processes tends to be different (86). These differences may be perceived as defects by the consumer, and manufacturers have been reluctant to alter a traditional product.

There are a number of advantages that the alternative systems have over the modern Fritz line (87). The most attractive advantage is the flexibility to produce a wide range of products, with fat contents ranging from 30% to 95% butter–vegetable oil blends and the ability to incorporate fractionated fats (88). The alternative processes also present the possibility of a number of operational advantages. The use of an efficient centrifuge during the cream concentration stage can substantially reduce fat losses in the buttermilk. The composition of the butter can be more

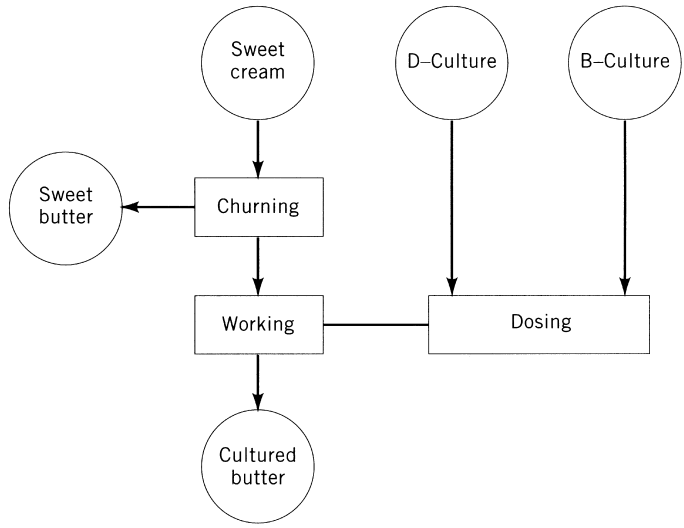

Figure 10. *Schematic of the Pasilac-Danish IBC method (81).*

accurately controlled, either by including a batch standardization step or by the use of accurate continuous metering systems.

5.7. Cultured Butter Manufacture

There are several ways of making cultured butter from sweet cream. Pasilac-Danish Turnkey Dairies, Ltd. developed the IBC method (Figure 10) (81). The main principles of the IBC method are as follows. After sweet cream churning and buttermilk drainage, a starter culture mixture is worked into the butter, which produces both the required lowering of butter pH and, because of the diacetyl content of the starter culture mixture, the required aroma. The starter mixture consists of two types of starter culture: (1) *Lactococcus lactis* and (2) *L. cremoris* and *L. lactis* ssp. *diacetylactis*. With respect to production costs, the experience with this method shows that, for the manufacture of mildly cultured butter, the direct costs are only about one-third of the costs of other methods (81).

5.8. Reduced Fat Butter

Fat shortages during World War II first stimulated interest in low-fat spreads in the United States. Oil-in-water spreads were first developed in the 1950s and 1960s. However, they had a number of limitations, including a shelf life of only 10–14 days (conventional butter shelf life is 4 months), a spongy texture, a lack of melting properties, and an inability to withstand freezing (89). The public's interest in low-calorie foods has motivated manufacturers to produce low-fat butter products. Although these products can no longer be called *butter* (according to international

standards), they are nonetheless often called low-calorie butter, half-butter, light butter, or a similar name. Many patents have been obtained for these products, because emulsifying properties are needed to deal with the water content (nearly 50%) of butter-like spreads. In addition, the emulsion must often be stabilized with additives. In some countries, a low-fat butter (40% total fat) containing vegetable oil has been designated as Minarine, but Minarine can also be prepared using only butter fat (62). Consumer interest in a reduction of additives in food products and a growing awareness of the importance of proper nutrition have created a demand for a low-fat product. It is now possible to produce a butter product based exclusively on butter fat with a fat content of 40%, without using emulsifiers. However, it is precisely this wish for a lower fat content in spreads and in other products that is forcing manufacturers to invest time and money in product development to find a use for their excess butter fat.

The first reduced-fat butter (50% fat), called Light Butter, was introduced in the United States by the Lipton Co. in the mid-1980s. The product was withdrawn due to FDA objections of not meeting Standards of Identity for nomenclature. Also, the product contained stabilizers not allowed for in the Standard of Identify for butter. In the late 1980s, Ault, Inc. introduced a reduced-fat butter (39% fat) called Pure and Simple, which contained no unusual additives (90). Unfortunately, this all-natural product had severe negatives: it had a short shelf life, experienced moisture seepage, and lacked the highly desirable butter notes. In 1990, Land O'Lakes, Inc. launched its Light Butter (52% fat), which contained emulsifiers, added Vitamin A, and preservatives. The FDA was in the process of establishing standards for reduced-fat products at this time and no objection was registered. The new standards were established in 1993 (63), which automatically required Land O'Lakes to reformulate to a 40% butter fat content; it did so and relaunched. The product was a success and has established dominance in the U.S. market.

Butter-like products with reduced-fat content are manufactured in several countries. Stabilizers, milk and soy proteins, sodium albumin or caseinate, fatty acids, and other additives are used. A product is now available on a commercial scale in the former U.S.S.R. that has the following composition: 45% milkfat, 10% nonfat solids, and 45% moisture. It has a shelf life of 10 days at 5°C (91). Each country has established its own standards for butter and butter fat products. Many are still developing standards for a reduced-fat butter product to meet the growing consumer demand.

Manufacturers have experienced many problems with the production of low-fat butter (92). Low-fat butter cannot be manufactured in conventional continuous butter makers. The technology of producing low-fat butter and margarine products is similar to that of ordinary margarine production, and it has nothing in common with modern butter (Fritz process) production (Figure 11). The conditions are, of course, more critical for products that contain only 40% fat. These low-calorie water-in-fat emulsions have such a dense package of water droplets that unwanted phase inversion during processing or structural weak points in the product can occur, which may, for example, severely limit the microbiological shelf life. The scraped-surface heat exchanger type of machine is preferred for production of low-fat products.

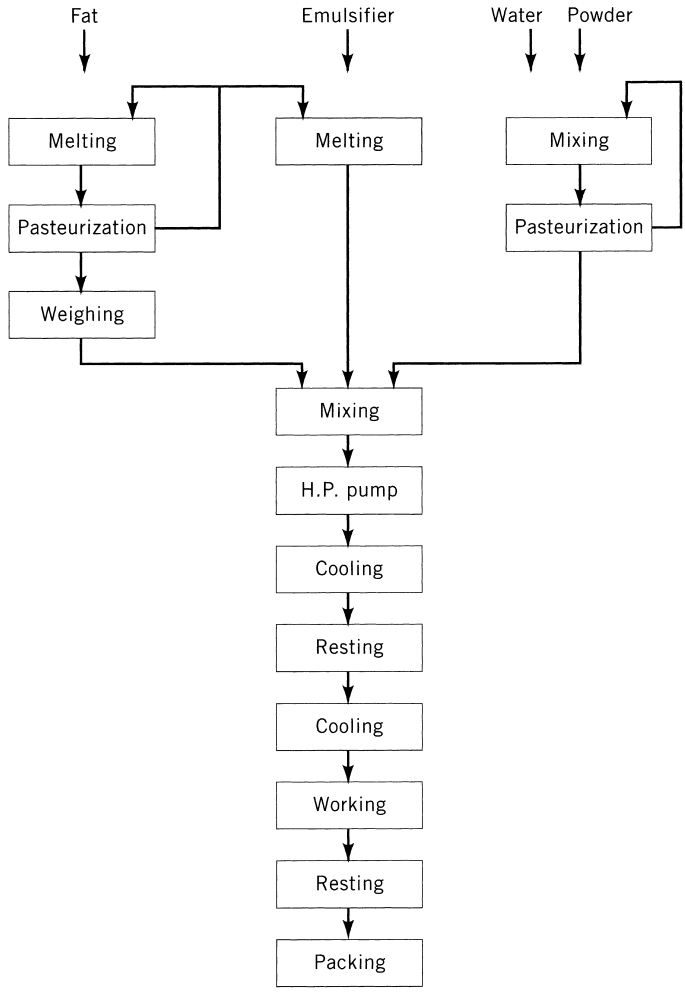

Figure 11. *Schematic for the production of low-fat butter and spreads (81).*

As a result of the close packing of the aqueous-phase droplets, the composition of the water phase is critical. Protein concentrates, caseinate, gelling agents, and special emulsifiers have been recommended to simplify the emulsification and to stabilize the end product (93–98). For manufacture, the basic material for production is a mix that is chemically identical to the end product. This mix consists of milkfat in the form of butter, butter oil, and fractionated butter oil or cream, in many cases, it also has milk solids, milk concentrates (including dissolved milk powder and caseinates), and emulsifiers (see Figure 10) (81). The fat mix (i.e., butter, butter oil, etc.) is melted and pasteurized.

The required amount is metered into an emulsion tank. If emulsifiers are used, they are melted and mixed with a small amount of fat before being transferred to the

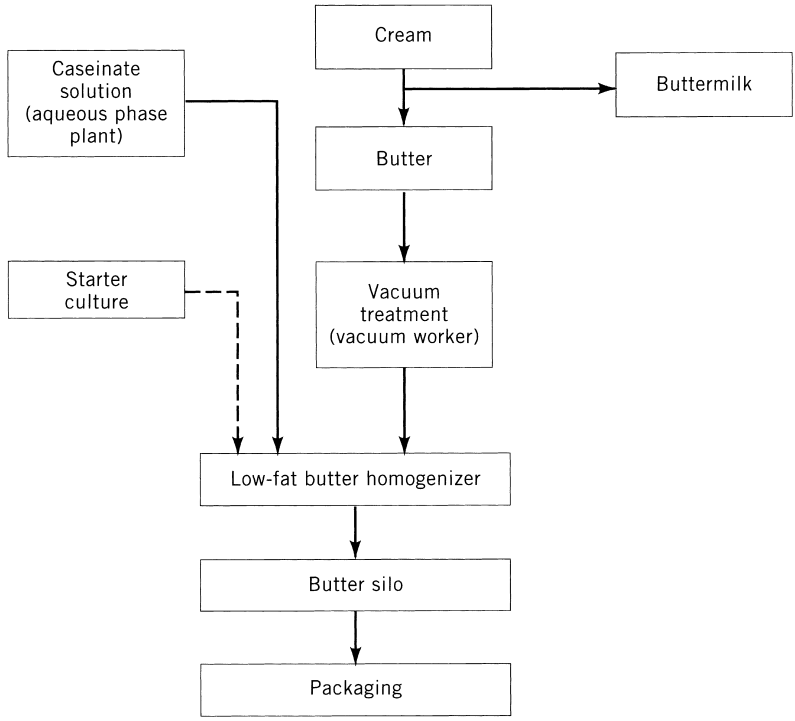

Figure 12. *Flow sheet of the APV Pasilac method (99).*

emulsion tank and added to the fat. The required amount of water is apportioned, nonfat milk solids are added, and the mix is pasteurized. The water–milk mix is transferred to the emulsion tank and mixed into the fat mix. The emulsion is then pumped to a specially designed scraped-surface cooler, where the emulsion, under heavy mechanical treatment and rapid cooling, is supercooled and crystallized, forming the water-in-fat emulsion.

Alternative methods have been developed. For example, the APV Pasilac method is widely used in Europe (Figure 12) (99). The continuous APV Pasilac method is quite simple. Ordinary butter with a fat content of 80–82% is mixed with an aqueous phase to the desired fat content. The mixture is then subjected to vigorous mechanical treatment in a special butter homogenizer, and the low-fat butter is ready for packaging. As Figure 12 shows, the low-fat butter equipment includes an aqueous phase plant. The production of the aqueous phase involves the following processes:

Dissolution of one or more powders in water–milk.

Pasteurization of the solution.

Cooling of the solution to emulsification temperature.

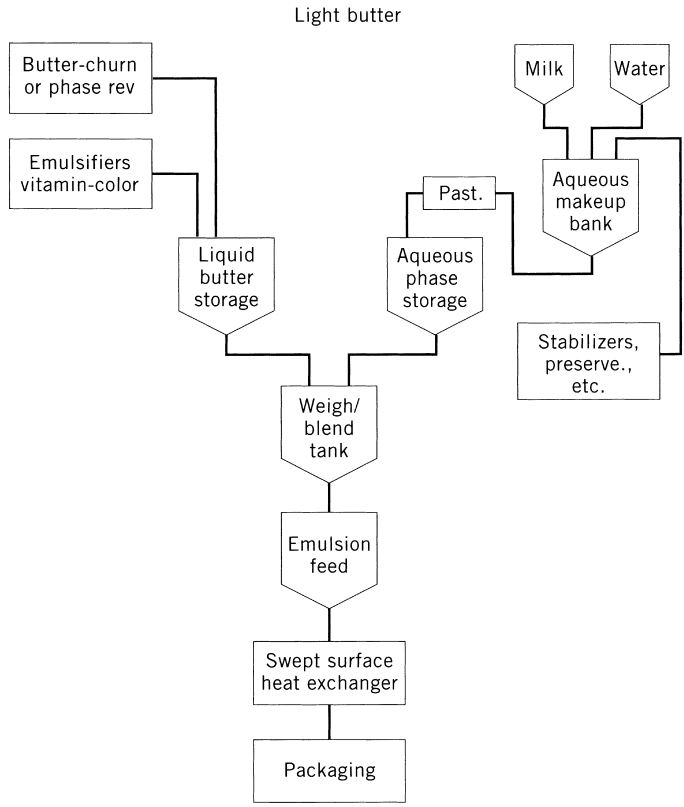

Figure 13. *Schematic of Land O'Lakes's method for the manufacture of Light Butter.*

The process makes it possible to manufacture a butter with a fat content as low as 28% (99).

Figure 13 shows the method used by Land O'Lakes to produce low-fat butter (40%). The method is similar to margarine manufacture.

Fat substitutes and zero-calorie fats offer the potential to reduce the total fat content of foods. Nutrition and marketing experts predict that consumers will show the same enthusiasm for fat substitutes as they exhibited for alternative sweeteners (100).

Figure 14 shows a schematic of the manufacture of a no-fat spread using modified whey protein concentrate (WPC).

5.9. Physical and Organoleptic Characteristics

Consistency. Consistency has been defined as "that property of the material by which it resists permanent change of shape and is defined by the complete force flow relation" (34). This implies that the concept of consistency includes many

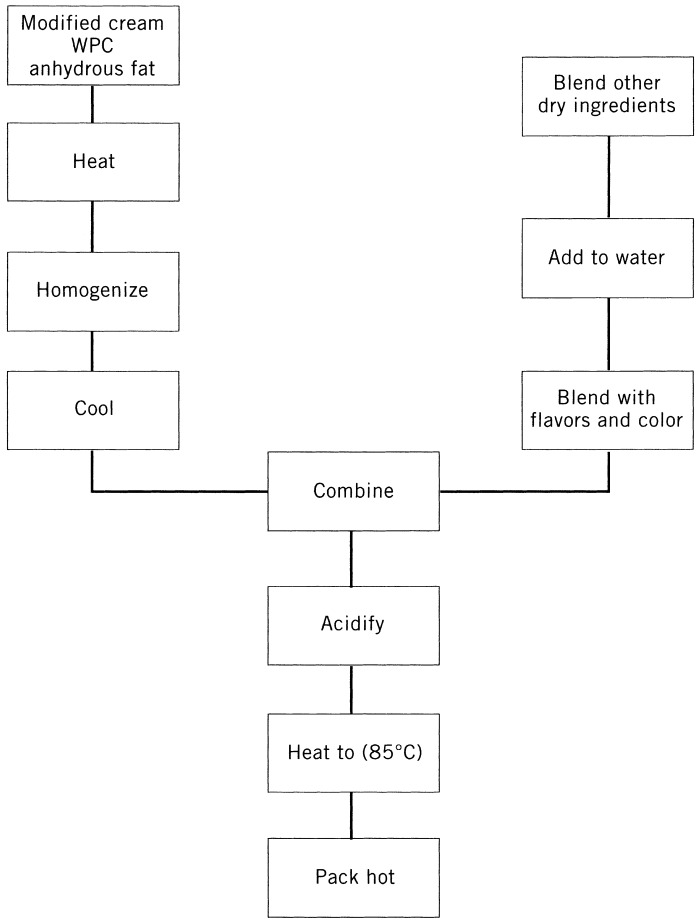

Figure 14. *Low-fat spread using modified whey protein concentrate.*

aspects and cannot be expressed by one parameter. Today, more importance is attached to spreadability than anything else in the evaluation of the consistency of butter. The general consensus is that butter should be spreadable at refrigerator temperatures. There is no suitable method available to measure such a subjective criterion as the spreadability of butter. For this reason, the firmness of butter, which should correlate well with spreadability, was selected as the parameter to be measured. It was recommended that the use of the cone penetrometer, along with other methods, could provide good results (101).

Flavor. One of the most important consumer attributes of butter is the pleasing flavor. Butter flavor is made up of many volatile and nonvolatile compounds. Researchers have identified more than 40 neutral volatiles, of which the most prominent are lactones, ethyl esters, ketones, aldehydes, and free fatty acids (102). The nonvolatiles, of which salt (sodium chloride) is the most prominent, contribute to a

balanced flavor profile. Diacetyl and dimethyl sulfide also contribute, especially in cultured butter flavor (103).

Body and Texture. By means of appropriate qualifications of the terms *body* and *texture*, butter graders describe the physical properties of butter that are noted by the senses. The exact meanings of these terms have not been clearly outlined. Frequently, they are used as if they had the same meaning. Certain properties such as hardness and softness refer to the body of butter, whereas properties such as openness refer to texture. However, some of the properties, such as leakiness or crumbliness, are confusing. Usually, most body and texture terms are used to describe a defect, e.g., gritty, gummy, and sticky (86). Good butter should be of fine and close texture; have a firm, waxy body; and be sufficiently plastic to be spreadable at cold temperatures.

Color. The color of butter may vary from a light, creamy white to a dark, creamy yellow or orange yellow. Differences in butter color are the result of variations in the color of the butter fat, which is affected by the cows' feed and season of the year; variations in the size of the fat globule; presence or absence of salt; conditions of working the butter; and the type and amount of natural coloring added.

Butter colorings are oil soluble and most often are natural annatto (an extraction of the seeds of the tropical tree *Bixa orellana*) or natural carotenes (extractions from various carotene-rich plants). Because they are oil soluble, colorings are added to the cream to obtain the most uniform dispersion.

5.10. Texturization and Spreadability

The most common method to improve the spreadability of butter is to incorporate air or nitrogen, generally increasing the volume by 33%. The product called whipped butter is sold in a tub rather than in stick form.

The consistency of butter is determined by the percentage of solid fat present, which is directly influenced by the fat composition, the thermal treatment given to cream before churning, the mechanical treatment given to butter after manufacture, and the temperature at which the butter is held (104). The European butter market demands that butter be softer and more spreadable in winter and harder in summer. With information on the changes in fat composition from gas–liquid chromatography analysis and the use of nuclear magnetic resonance to estimate solid fat, suitable tempering procedures can be selected to modify the fat composition and to produce the most acceptable product for the consumer. A spreadable consistency of butter can be achieved by either varying the fatty acid composition or varying heat-step cream-ripening times and temperatures (105). There are a number of recognized processing options available that influence butter spreadability. Examples include mechanical treatment (texturization) (104, 106–109), temperature profiling of the cream (Alnarping) (85), blending winter and summer butters (107), fractionation of the anhydrous milkfat (37, 110–113), interesterification of the fatty acids (105, 114), the diet of the cow (38, 115–117), and cream ripening (118). When blending butters, it is important to understand milkfat melting and solidification curves (Figure 15).

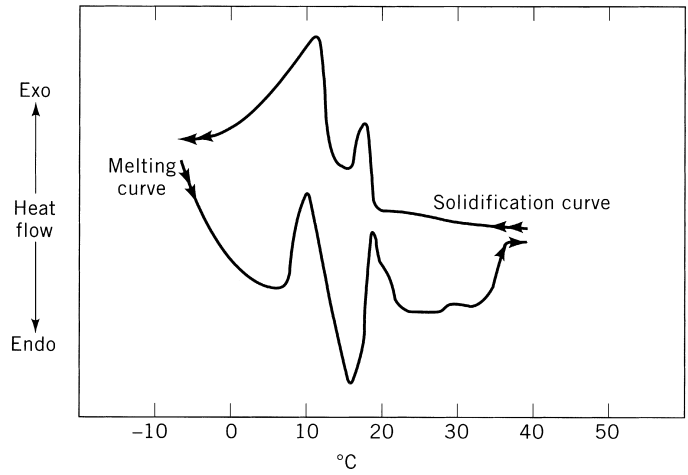

Figure 15. *Typical milkfat melting and solidification curves obtained by differential scanning calorimetry (107).*

Mechanical treatment, or working, involves physically disrupting the three-dimensional fat crystal network and breaking the bonds between the crystals. It is essential that this mechanical treatment is applied to butter in which the crystallization has been totally completed (usually 7 days after churning). The primary crystal structure is strong, and once it is destroyed by kneading it does not reform easily. A new, secondary structure is then formed. This structure is weak and reforms quickly after having been destroyed by kneading.

In the Netherlands, bulk butter is often processed in a Mikrofix homogenizer to give it more plastic structure before it is repackaged for retailing (109).

The first published cream tempering process (1937) was developed by the Alnarp Dairy Institute in Sweden, which lent its name to this and similar processes (107). In the original Alnarp process, pasteurized cream was cooled to 8°C for 2 h, warmed to 19°C for 2 h, and then cooled to 16°C and held until churning. Modifications allowed for initial cooling of the cream to initiate nucleation of the crystals at a temperature well below the main solidification temperature ranges (see Figure 14). The cream was then warmed to a temperature several degrees above that of the lower melting peak temperature to encourage a fractionation process in which high-melting glycerides crystallized and low-melting glycerides melted (Figure 16).

Another alternative to increasing butter spreadability is providing cows with specific feeds to change the fatty acid composition. The main opportunity for varying fat composition comes in the indoor feeding period, when cows receive some type of concentrate in addition to silage. If, for example, free soy oil is added to the diet, its constituent 18:2 and 18:3 fatty acids are converted in the rumen largely to 18:0 and some 11–18:1-*trans* (vaccenic acid). The gut wall and mammary gland contain a desaturase, which converts 18:0 to 11-*cis*-18:1. The milkfat resulting from such a diet may contain up to 60% of C18 acids, with 18:1 (*cis* and *trans*) assuming the

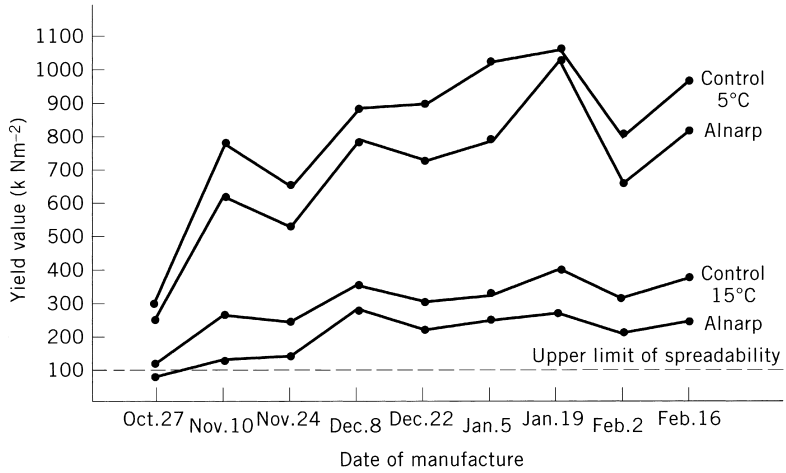

Figure 16. *Effect of Alnarp-type treatment on firmness of winter butter (107).*

dominant position. The milkfat contains a relatively low proportion of 16:0, 14:0, 12:0, 10:0, and 8:0, because of the depression of *de novo* synthesis within the gland. The weight proportion of 4:0 remains fairly constant (which implies that the molar proportion may increase slightly) and that of 6:0 decreases only slightly, both facts indicating that 4:0 and 6:0 are synthesized by a route that is relatively much less significant (38, 114, 116, 117). As a result of the high unsaturated C18 fatty acid content, this type of milkfat has a lower melting spectrum. The outcome is a butter that has reasonable spreadability at refrigeration temperatures (114).

Feeding protected unsaturated fat usually leads to an increase in the proportion and yield of milkfat. However, a major cost is, in this instance, associated with the preparation of the feedstuff, involving as it does homogenization of an oil–water–protein mixture and the subsequent removal of the water by spray drying. This type of feeding practice has little commercial application at present (116). Thus, although the scientific knowledge to alter the fatty acid composition of milkfat is well established, economic considerations have prevented its exploitation.

In efforts to improve the spreading properties of butter in relation to hard butter fat, one alternative put forward is the use of softfat fractions obtained in the fractionation of anhydrous milkfat. Although several practical methods of fractionation have been presented, the use of softfat fractions in buttermaking has not become general practice. This is evidently because fractionation in all cases significantly raises the cost of the butter produced. In addition, a common problem has been to find suitable uses for the hardfat fractions. Furthermore, in fractionation methods that use solvents or additives, fractionation should be linked to fat refining, and, in this process, butter also loses its natural food classification. In studies that have used soft butter fat fractions, a substantial softening of the butter has been obtained; however, this butter, like normal butter, hardens as the temperature increases and again decreases (118). As milkfat exhibits a wide melting range from about $-30°C$, it may be possible to use a dry fractionation process. Suitable sizes of crystals are

developed by controlled cooling of the melt, and the crystals are separated from the liquid phase by filtration or centrifugation. The fractionation of milkfat by melt crystallization has been extensively studied (37). The general conclusions from these investigations were as follows: the short-chain triglycerides and the short-chain and unsaturated long-chain fatty acids were enriched in the liquid fraction; the efficiency of molecular size separation in the melt crystallization process was poor; and the flavoring compounds, pigments, Vitamin A, and cholesterol were slightly concentrated in the liquid fraction.

Currently, dry fractionation of anhydrous milkfat is performed by two conventional systems—Tirtiaux and De Smet (both from Belgium)—which are bulk crystallization processes. The widely used Tirtiaux dry fractionation process enables one-step or up to five-step fractionation of anhydrous butter oil at any temperature, ranging from 50°C to 2°C (37, 110–113). The milkfat fractions thus obtained can be used as such or the fractions can be blended in various proportions for use as ingredients in various food-fat formulations. The major shortcoming inherent in this system is the long residence time (8–12 h) for nucleation and crystal growth.

Butter samples made from low-melting liquid fractions and from a combination of primarily low-melting liquid fractions and a small amount of high-melting solid fractions exhibited good spreadability at refrigerator temperature (4°C) but were almost melted at room temperature (21°C). Butters made with a high proportion of low-melting liquid fraction, a small proportion of high-melting solid, and a small proportion of very high-melting solid fractions were spreadable at refrigerator temperature and maintained their physical form at room temperature (Figure 17).

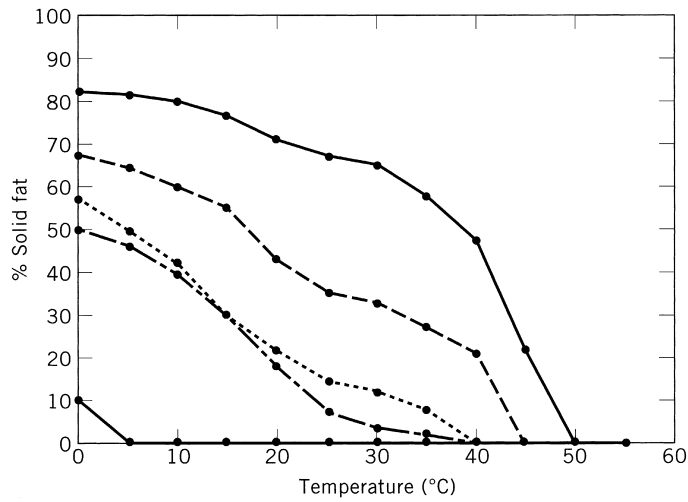

Figure 17. *Solid fat content profiles of the control and anhydrous milkfat (–·–·–); the low-melting, high-melting, and 20% very high-melting milkfat (· · · · ·); and the milkfat fractions used in the low-melting, high-melting, and 20% very high-melting butter: 30S fraction (——), 13L fraction (—, bottom line), and 15S fraction (—, top line). The fraction number includes the fractionation temperature (°C) and its physical form (solid or liquid) (110).*

A pourable butter, formulation, nonfractionated at room temperature has been reported in the patent literature (119).

5.11. Anhydrous Milkfat Manufacture

The quality assurance program for manufacture of butter oil, or anhydrous milkfat (AMF), also focuses on the quality of the raw materials. Naturally, many of the same considerations apply to handling raw cream for AMF manufacture that apply to butter, except that vacreation is not used. As it is stored under ambient conditions, care against oxidation is essential. Oxidation is perhaps the most important mechanism by which milkfat deteriorates in quality. As the oxidation reaction is autocatalytic (i.e., the products of the reaction act as catalysts to promote further reaction), the normal quality-control tests, peroxide value and free fat acidity, could give misleading results when applied to stored butter. Methods of deaeration have been developed that could reduce potential oxidation (74).

Milkfat is present in milk or cream as part of a stable oil-in-water emulsion. The emulsion is stabilized as a result of the protein and phospholipid-rich milkfat globule membrane (MFGM) surrounding the milkfat. During AMF manufacture, the aim is to break the emulsion and to separate out all of the nonfat solids and water (Figure 18). To achieve this, the MFGM must first be disrupted mechanically or

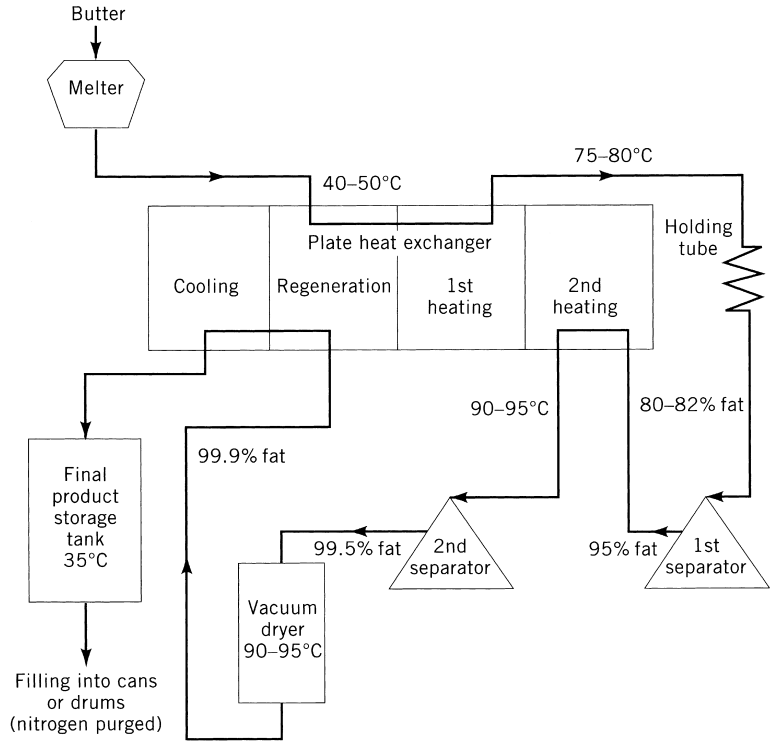

Figure 18. *Anhydrous milkfat manufacture (120).*

chemically. Homogenization, an example of mechanical treatment, disrupts the membrane, destroying the membrane layer. For chemical destruction of the membrane layer, an acid such as citric acid can be added to lower the pH of milk or cream to about 4.5 (120). The protein will precipitate, removing a component to maintain an intact fat globule. Direct-from-cream AMF plants usually have three separators. The first concentrates cream from 40% to about 75% fat before phase inversion in a homogenizing device. The oil separator then separates the liberated butter oil to about 99% purity. The oil is washed with water before the third (polishing) separator, and the final traces of moisture are removed in a dehydrator at 95°C and under a vacuum of 35–50 torr. The dehydrator is usually a simple vessel, and the butter oil is introduced either as a thin film on to the walls or as a spray, to maximize the surface area exposed to the vacuum. Such a device will not remove significant off-flavors, because the vapor flows, temperatures, and pressures are inappropriate for flavor stripping. When producing AMF from butter, fresh or block butter is softened just to a pumpable stage (approximately 50°C) and transferred to a plate heat exchanger to increase the temperature (70–80°C). The oil phase is concentrated through separators and dried under vacuum. Some washing is possible before the final separator removes the last traces of nonfat components (see Figure 18).

In terms of the preparation of products and their appearance and texture, AMF has several advantages over traditional butter. The latter is, in fact, subject to seasonal variations, which affect its physical properties. The advantages of AMF are linked to the possibility of standardizing its physical properties (by the selection and mixture of the raw materials used in production) and the possibility of adapting its properties using the fractionation technique. This is particularly important for its use on an industrial level where, given the automation of production and the standardization of the texturization stage (temperature), it is necessary to maintain constant physical (rheological) and organoleptic properties (121).

5.12. Packaging

The objective of any packaging system is to protect the product from deleterious environmental conditions. Many packaging systems have been developed to protect the milkfat from biological, chemical, and mechanical deterioration. Bulk containers, such as 5-L cans and 20- and 25-L drums, are popular for packaging industrial materials such as butter oil and AMF. These containers usually have a welded side seam and are plain internally. Unlike edible oils, milkfat is corrosive to tinplate, so an internal gold epoxy phenolic lacquer, such as International Paint's "IP 180," is required. If the containers have a welded side seam, the internal raw steel edge of the weld needs to be protected by applying a side-strip lacquer (i.e., a two-part epoxy polyamine). All lacquers used on food cans should have FDA status (122). Larger drums (i.e., 210-L nominal and 218-L maximum capacity) need more rigid walls to withstand the greater mechanical stresses in handling. When chilled storage is available, less rigid forms of packaging may be used. Concentrated butter is now being retailed for domestic cooking, aided by a European Community subsidy. This

concentrated butter is normally packaged in either parchment or a foil–parchment laminate similar to that used for butter (123).

For packaging in foil, parchment, or other flexible film, the milkfat needs to be in a plastic state, similar to that of freshly churned or reworked butter. The optimum softness of the fat depends on the packaging system being used. Traditionally, the United States has packaged consumer portion sizes of individually wrapped four 0.25-lb sticks in 1-lb units. Multiple sizes from 5 g to 25-g units of foil-wrapped ''continentals'' or polyethylene molded cups, have been used in the food service sector. For bulk handling, the plastic fat or butter can be packed into polyethylene-lined fiberboard boxes. In all cases, the aim is to fill the desired quantity of fat with the minimum giveaway. Aeration of the milkfat should also be avoided as oxidative rancidity is the principal factor limiting the shelf life.

5.13. Storage and Transport

Storage conditions depend on the end use for the product, the packaging system, and the desired storage time. Milkfat in hermetically sealed cans and drums is the least affected by its storage environment. Ambient storage is commonly used and must be to the same standards as used for other food stuffs (122). In the European community and the United States, temperature is not a major factor, but it can be in tropical countries, where the temperature may rise to 35–40°C. At temperatures in excess of 30°C, the milkfat deteriorates significantly more rapidly, and there is an increased risk that the stored fat will have a stale, oxidized off-flavor.

Transport of drums and cans may be at ambient temperature, though the storage life may benefit from refrigeration. High humidity and wet conditions should be avoided to minimize the risk of corrosion or mold growth on the packaging that would entail an additional cleanup operation. The drums should be stowed away from excessive heat and noxious chemicals. For most journeys, standard freight containers may be used.

Milkfat in polyethylene-lined fiberboard boxes is at a far higher risk from its storage environment. As the packaging is permeable to oxygen, the product is more prone to oxidation. Chilled storage (10°C, preferably 5°C) must be used both to reduce the rate of oxidation and to maintain the rigidity of the pack. The humidity of the storage area must also be controlled to prevent mold growth on the fiberboard. As the pack is also permeable to odors, the storage area should not be shared with other food stuffs with strong odors that could cause off-flavor absorption (e.g., fish, onion, garlic).

Flavor transmission and oxidation are less of a problem at temperatures below −20°C, which is preferable for long-term storage. When conserving and preserving stocks of butter for extended periods (5 years or more), a process has been developed by which butter is placed in the refrigerated chamber or warehouse, which has been sealed airtight. The air is evacuated and replaced with nitrogen or other inert gas mixture so that the pressure in the chamber is equal to the exterior atmospheric

pressure. This process allows for extended storage without mold growth and development of rancidity (124).

When butter has been frozen, textural characteristics may have been deleteriously affected. An invention to improve texture has been described in which large, deep-frozen blocks of butter with the desired moisture content are reworked by chipping them in a butter chipper while adding measured quantities of water. The butter chips are then fed through a vacuum chamber into a butter churn designed as a continuous kneading mill. The butter chips are continuously conveyed under pressure through the kneading mill by means of a high-pressure butter pump (125).

It is not possible to set rigid standards for the shelf life of milkfat. Shelf life depends primarily on the acceptance quality criteria of the user and will be affected by (1) the quality of the feedstock, (2) the packaging system, and (3) temperature. With increasing storage time, the flavor defects are more likely to become noticeable. Flavor does not correlate easily with peroxide value (126). At a peroxide value of <0.6, oxidized flavors are unlikely, but if the peroxide value is >1, then some oxidized flavor may be expected. It must be pointed out that these figures are based on the International Dairy Federation (IDF) method (127) for measuring peroxide value and that other methods are likely to give different results. Other grades of milkfat defined in the IDF standard are anhydrous butter oil and butter oil. Anhydrous butter oil is the product obtained from butter for cream; it may be of different ages and should have no pronounced, unclean, or other objectionable taste or odor. Butter oil is the product obtained from butter or cream; it may also be of different ages and should have no pronounced, unclean, or other objectionable taste or odor.

6. BUTTER FAT PRODUCTS

6.1. Butter Fat–Vegetable Oil Blends

The first commercial development of a spread made from a combination of butter fat and vegetable oil was in Sweden in 1963. The product, Bregott, contains 80% fat, of which 80% is milkfat and 20% is soybean oil (128). Bregott is a margarine according to Swedish and American food standards. Swedish scientists also developed and successfully commercialized the first reduced-fat spread in Europe in 1974. The product, Latt and Lagom, contains 39–41% fat, of which 60% is milkfat and 40% is soybean oil. It is considered to be a low-calorie margarine. Bregott is exported to Australia, and Latt and Lagom to Japan and France (89). In Finland, where Bregott is popular, oil from rapeseed is used (83).

Other products (under license from the Bregott patent) are Voimariini in Finland, Bremykt in Norway, Smjorvi in Iceland, and Dairy Soft in Australia. Similar products are Clover in the U.K.; and Dairy Gold, Kerry Gold, and Gold'n Soft in Ireland. This list is, however, not complete. The latter blends are high-fat products (75–82% fat), and the amount of butter fat of the total fat is about 50% (93). Most of these products are manufactured in a churning process in a churn or a continuous butter machine.

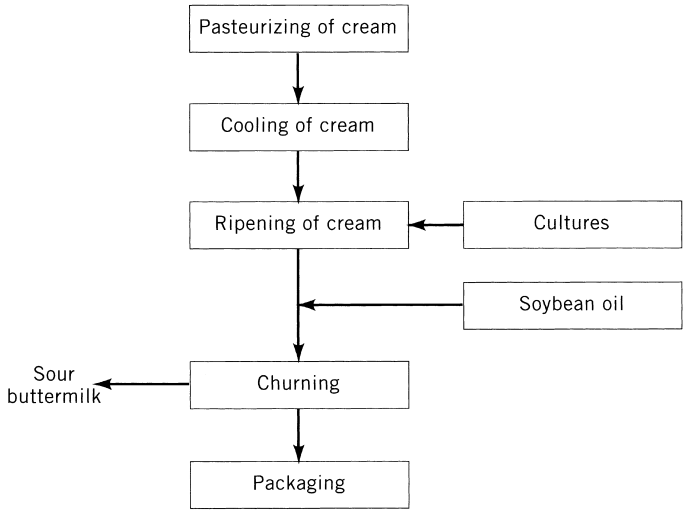

Figure 19. *Flow diagram of the manufacture of butter–vegetable oil mixtures (93).*

The first steps in the manufacture of Bregott are pasteurization of the cream, followed by cooling and temperature treatment. The cultures are the same as those used in buttermaking. Measured quantities of cream and soybean oil are mixed in the churn or the oil is continuously injected before churning in a continuous butter machine. The byproduct is sour buttermilk.

The most commonly used vegetable oil is soybean oil. Products with a low percentage of butter fat will contain not only vegetable oil but also hydrogenated vegetable fats to achieve a good plasticity. If the minor part of the total fat is butter fat, as in Golden Churn from the U.K., the manufacturing process is completely different from modern butter production. In this case, the technology is analogous with normal margarine manufacture, where some part of the fat is replaced with butter fat. The emulsion is cooled in scraped-surface coolers (Figure 19).

Very low-fat spreads have recently been developed. The first European commercialized product was made by St. Ivel and is called St. Ivel's Lowest. It contains 25% butter fat and has a lower saturated fat content than sunflower margarine (129).

In the early 1980s, blends of butter and vegetable oil products appeared in the U.S. market. The U.S. market leader was Country Morning Blend made by Land O'Lakes. These blends generally were 40% butter and 60% vegetable oil for a total fat content of 80%, within the margarine Standard of Identity and designation. With the increasing popularity of reduced-fat (less than 80%), spreads, starting in the mid-1980s, other blends with butter fat contents of 2–25% were introduced. The 80%-fat margarine blends are losing market shares to lower fat spreads and blends (130).

A number of processes have been developed using continuous churns (97) and alternative systems similar to the Cherry-Burrell Gold'n Flow process (98). The major disadvantage to churning, either batch or continuous, is that the resultant

buttermilk is adulterated with some vegetable fat and is less valuable than standard buttermilk. An advantage of alternative processing systems is their ability to accommodate easily the manufacture of reduced-fat spread blends. All butter fat–vegetable oil blends provided alternatives to butter for the consumer when concerns of health (e.g., fat saturation) and spreadability are desired.

6.2. Ghee

By definition, ghee is a product obtained exclusively from milk or fat-enriched milk products of various animal species by means of processes that result in the near total removal of water and nonfat solids (similar to anhydrous milkfat) and in the development of a characteristic flavor and texture. Even so, most ghee contains some nonfat solids to enhance the flavor.

Typically, ghee is manufactured by heating butter to temperatures well above those used during AMF manufacture. The high-temperature treatment of the nonfat milk solids and milkfat leads to the development of a strong buttery flavor. However, traditional ghee, as produced in the Middle East and Asia, has a more rancid taste due to less sophisticated methods of preparation and storage. Manufacturers in the European Community are also producing ghee by adding ethyl butyrate to anhydrous milkfat (119, 131). Alternative synthetic flavors have been developed to add ghee flavor notes to butter oil.

A synthetic mixture consists of δ-G_{10} lactone (3 ppm), δ-G_{12} lactone (15 ppm), decanoic acid (5 ppm), and kenanone-2 (10 ppm). This technique is simpler, less time-consuming, and more economical that the technique that uses powders. The shelf life of this flavored butter oil is 2.5 months. However, the addition of synthetic antioxidants, butylated hydroxyanisole (BHA) at the 0.02% level, enhances its shelf life so it can compete well with conventional ghee (131).

6.3. Butter Fat as an Ingredient

Recombined Products. For recombination of milk and dairy products, the two primary ingredients required are AMF and nonfat milk solids. A range of fat sources is available for the recombining industry, but only a few of these are in widespread use. In most countries, anhydrous milkfat is usually the sole fat source. Numerous products can be made by putting together the correct proportions of water, flavor, and other ingredients as desired (e.g., sugar, emulsifier, and stabilizers) to make sweetened condensed milk, ice cream, recombined butter, or milk (1%, 2%, or full-fat). For these applications, AMF of the highest quality should be used to avoid off-flavor development. The recombination of butter has been reported in detail (132).

In response to the problems associated with the handling of unsalted butter, a new milkfat product was developed in New Zealand to combine the superior flavor of butter with the ease of handling of AMF. Initial shipments of this product, fresh frozen milkfat for recombining (FFMR) were favorably received, and FFMR quickly became established as the preferred alternative to unsalted butter (72).

Pastry, Cake, and Biscuit Products. In general, fats play several essential nutritional, technological, functional, and organoleptic roles in most all-bakery applications. As a result of its physical properties, fat plays a major part in the production of the majority of items in the pastry, cake, biscuit, and chocolate confectionery sector; for example, in the preparation of pastry cream and in the desired appearance and texture of the end product. These physical properties include, above all, the rheological properties (consistency, plasticity, texture, etc.), and the properties of fusion and crystallization depend on the type of fat, the temperature, and the working conditions of the product.

The fats used in pastry and biscuit confectionery have different functions, which are determined by their rheological properties (plasticity and texture). In pastry, these principal functions are (1) an increase in the plasticity of the pastry (e.g., hard pastry with a low level of hydration) and (2) a break in the body of the pastry (i.e., the fat makes the gluten structure discontinuous, which gives the desired crumbliness in, for instance, biscuits) (121).

Confectionery–Liquors and Liqueur. In chocolate confectionery and for pastry creams, it is the physical properties linked to the fusion and the crystallization of the fat that are essential. For milk chocolate, for coating or in bars, AMF can be used in proportions that depend on its compatibility with cocoa butter, whose properties of hardness and rapid fusion at 35°C cannot be altered. Thus it is currently accepted that AMF with high fusion levels obtained by the fractionation technique can be used. In general, milkfat has an interesting characteristic: it inhibits the appearance of fat bloom (133).

For pastry creams, the ideal is an AMF, which causes rapid melting in the mouth. Depending on the type of pastry cream, a wider choice of AMF can also be offered, thanks to the fractionation technique.

Due to the low level of milkfat in dark chocolate, fat bloom is a problem with this product. The hard fraction of milkfat (milkfat stearin) has been reported to act as an antibloom in dark chocolate, giving the chocolate an increased shelf life. However, the use of hardened milkfat is limited in several major chocolate producing countries (133).

Regulations for the amount of milkfat, nonfat milk solids, whole milk solids, and total milk solid allowed in milk chocolate vary among countries. Fats other than milkfat are allowed in milk chocolate in some countries, although different flavors and textures may result in the chocolate.

Although the preferred source of milkfat in cream liqueurs and associated beverages is undoubtedly double cream, its use may lead to problems. In particular, cream contains calcium and other ionic materials. One solution is to wash the cream to remove all ionic materials, but this approach is cumbersome in practice. The preferred approach is to use anhydrous butter fat as the starting material.

Other Uses. The use of butter or anhydrous milkfat requires more added emulsifiers in ice creams and ice milks, because the naturally occurring milkfat emulsion will have been destroyed in the manufacturing process. Milkfat is also used in fresh cream, frozen cream, dry cream, and plastic cream. Ice creams contain a high level of milkfat, and its manufacture uses substantial quantities of milkfat worldwide.

6.4. Butter Fat Powders

The main purposes of transforming fats into powdered forms are to increase their microbial stability and to enhance their handling and functional properties. Powdered fats are available in two principal forms. The first form is feasible only if the fat contains sufficiently large amounts of high-melting compounds. If a fine jet of molten fat is sprayed into an ambient atmosphere, it will set as fine discrete particles. The second form embodies the use of a carrier. This form is necessary for oils and fats, such as milkfat, that contain appreciable amounts of low-melting triglycerides. The carrier can be added to the fat before or after spraying.

Dry creams are commonly produced as an ingredient for many applications. They consist of at least 40% butter fat, but can range up to 70% fat, 22–57% nonfat milk solids, and 0.5–5% moisture.

The Commission for Dried and Condensed Milk of the International Dairy Federation (1962) proposed to designate cream powders of 60% or more milkfat as ''butter powder.'' Later, it was suggested that a minimum of 80% milkfat be used for butter powder (134). Butter powder composition can vary in the amounts and types of the nonfat constituents, depending on the application. Powders can include nonfat milk solids, sodium caseinate, sodium citrate, sodium aluminum silicate, sucrose, and lactose (134). Other possible minor constituents are antioxidants, emulsifiers, flow agents, and stabilizers. The objective is to create a stable, fluffy, free-flowing, nongreasy, and loose creamy powder. Butter powder containing 80–85% fat could not possibly meet the legal and organoleptic texture requirements of butter when reconstituted with water; therefore, it is not in market competition for conventional butter use. The potential applications for high-fat powdered products include butter-like spreads, coffee or beverage whiteners, soup, sauce and dessert creamers, convenience ice cream, scrambled eggs and omelettes, pudding and pancake mixes, and aerating fats.

6.5. Specialty Butter Fat Products

Flavored Butter. Flavored butters (garlic, onion, pepper, lemon, etc.) have been successfully mass marketed in Europe (135), but this success has not translated to the U.S. market. There exists a limited specialty market in upscale stores and delicatessens and certain food service applications. Manufacture is quite simple. Creating the desired flavor blends remains an art and skill.

Hypoallergenic Butter. A U.S. patent was granted in 1992 for the manufacture of hypoallergenic butter (136). The patent has limited claims. The product is a sterile butter-like product made from anhydrous milkfat; it contains no nonfat solids (99.9% free of NFS).

Butter Flavors. Technologies for the hydrolysis of butter fat to produce and concentrate the free fatty acids to enhance the butter flavor of products have been available for decades. More recently, biotechnologists have developed methods for producing a variety of fairly pure enzymes, economically and in large quantities. The increased availability of lipases (glycerol ester hydrolases) from microbial

sources has made it possible for researchers to employ the catalytic properties of these enzymes in innovative ways. One application in which the use of lipases has become well established is the production of lipolyzed flavors from feedstocks of natural origin.

Immobilization of lipases on hydrophobic supports has the potential to (1) preserve, and in some cases enhance, the activity of lipases over their free counterparts; (2) increase their thermal stability; (3) avoid contamination of the lipase-modified product with residual activity; (4) increase system productivity per unit of lipase employed; and (5) permit the development of continuous processes. As the affinity of lipases for hydrophobic interfaces constitutes an essential element of the mechanism by which these enzymes act, a promising reactor configuration for the use of immobilized lipases consists of a bundle of hollow fibers made from a microporous hydrophobic polymer (137).

Extended-life Creams. Extended-life creams are produced using normal separation techniques but involve a high-temperature, single- or double-heat treatment (95–135°C). The temperatures employed render the product almost sterile. Any surviving bacteria tend to be spore forming types. Packaging is usually carried out on aseptic machines or nonaseptic machines modified with, for example, H_2O_2 spray and ultraviolet lights (76).

Short-life Creams. For short-life creams, the shelf life depends on a low-bacteriological-count milk with good plant hygiene. Heat treatment tends to be in the region of 75–90°C with 3–30 s hold, followed by cooling to below 10°C. Final cooling to below 5°C is normally carried out in aging tanks or in the retail container in the cold store. Shelf life can be up to 12 days (76).

Ultrahigh Temperature Creams. Heat treatment for ultrahigh temperature (UHT) creams is produced by indirect or direct heating to 135–140°C with 1–4 s hold before cooling to ambient temperature. Aseptic packaging is essential. As this product is designed for long shelf life (3–4 months), formation of a cream plug or fat rise in the container must be avoided. Hence, all UHT creams, including whipping cream, must be homogenized. Homogenization can be carried out either upstream or downstream. If carried out downstream, an aseptic homogenizer must be employed (76).

Decholesterolized Milkfat. In the 1980s, there was significant research and market activity in developing decholesterolized milkfat. All this activity was for naught, for the hypothesis of creating a ''healthier'' fat (for butter or milk or other dairy product) was not sound. The nutrition community had long recognized that the link between dietary cholesterol and serum cholesterol was weak and that the ratio of total fat-saturated fat had a greater impact on health. In addition, the FDA issued new standards in 1993 (63) that effectively negated the value of decholestering milkfat. The new law required that, to be called low cholesterol, the fat must contain no more than 2 g of saturation fat per serving. Butter fat is approximately 65% saturated. As the technology to desaturate milkfat is not cost-effective, decholesterization has no economic value.

Desaturated Milkfat. In addition to chemical and enzymatic means of desaturation, there have been extensive studies on feeding cows specific diets to change

butter fat saturation as well as increasing the ratio of potentially desirable fatty acids (38, 115, 116). In general, good progress in the understanding of rumen physiology, digestion, and function has occurred, but economic potential remains unacceptable. The most promising technologies are the use of protected fats in a feeding regimen. These fats are protected in a way that they pass through the rumen (point of fat hydrogenation) into the remaining digestive system for absorption and subsequently into the mammary glands. Unsaturated fats that are fed to cows have a great opportunity to remain unsaturated as they are synthesized into milkfat. Biotechnology may offer alternatives in the modification of edible fats and milkfat. Research has led to new methods of lipolysis and esterification, but the developments are still at the laboratory level. Nevertheless, commercial application may emerge from these interesting areas of research.

Nutraceauticals and Healthy Fats. Almost all dairy products tend to be excellent carriers of specialized nutrients (vitamins, minerals, specialized cultures, and micronutrients), thus there is potential for fortification to enhance the natural nutritive properties of dairy products, creating nutraceauticals or functional foods. The use of specialized cultures such as *Lactobacillus acidophilus* and *Lactobacillus bifidus*, which have generally recognized nutritive characteristics, is ideal for cultured butter. A butter spread product using these cultures (Fittisport) has been launched in the French market; another with lower fat content has been introduced in the German market (138). In addition, it has been shown that the free fatty acids of milkfat have inhibitory effects against certain pathogens (e.g., *Listeria monocytogenes*) (139).

A structured, lipid-containing dairy fat is covered by a U.S. patent (95). The invention relates to a *trans*-esterification product of a mixture of fatty acids and triglycerides, including milkfat, in the form of cream or butter as the main component. The product has nutritional applications and may also be used as an enteral or parenteral supplement.

Nonfood Applications. The nonfood use of milkfat has been insignificant. Milkfat and milkfat fractions could, however, have some potential possibilities for profitable use, for example, in manufacture of pharmaceutical or technochemical products. Land O'Lakes, in association with Amerchol, has pioneered the use of milkfat fractions in cosmetics. The first product, called Cremoral, was launched into the marketplace in 1993 (140). The major factor that has stimulated renewed interest in using milkfat for technochemicals and other nonfood applications in the United States has been the significant decline in price, especially relative to alternative fats.

It is doubtful if any single market for milkfat can be found that will compensate for the decrease in butter sales. Rather, it will be necessary to look for a large number of relatively small outlets. If this is to be done, the dairy industry must understand the detailed structure of milkfat and establish the functional properties of its constituent fractions. This approach has been applied with considerable success to the protein fraction of milk. It may be just as rewarding when applied to milkfat.

7. ECONOMICS

Production and consumption of butter continues a long-declining trend. U.S. production of butter for 2001–2004 is given in Figure 20 (141). A dramatic shift occurred, starting in 1985, to the table spreads category of products (less than 80% fat) from full-fat butter, margarine, and blends (88). The spreads category encompasses all non–Standard of Identity table spreads (i.e., 0–79.9% fat).

In a 1984 survey, the most important barriers to increased butter sales were listed in the following order (88):

Price (opinion of an overwhelming majority when butter is compared with margarine).

Health (negative consumer attitudes toward cholesterol and saturated fats are increasing).

Poor spreadability.

Inadequate promotional spending.

Product innovation in margarine and spreads.

Legislation and regulatory restrictions.

Butter manufacture continues to serve as the safety valve for the dairy industry. It absorbs surplus milk supply above market requirements for other dairy products. Milk not required by the demand for these products overflows into the creamery, is skimmed, and the cream is converted to butter. When the milk supply for other products runs short of their demand, milk normally intended for buttermaking is diverted into the channels where needed. Even though consumption patterns have

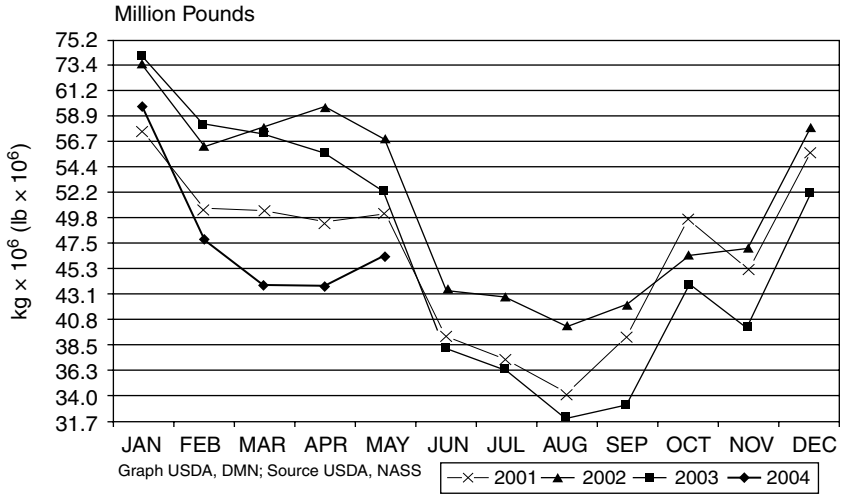

Figure 20. *Per capita consumption of butter and margarine in the United States, 1968–1993.*

dramatically changed over the years, the butter industry never fails to take up the slack in the relationship of supply and demand for all other dairy products.

Butter is both an intervention and a market product. To counteract growing stocks, special uses are created within the scope of the milk market organization, which contribute to not having too much butter in common storage. For some years now, between 300,000 and 400,000 tons of butter have been sold annually at reduced prices to the cheese pastry, ice cream, and chocolate industries in competition with vegetable fats (142).

Despite this and other measures, it was not possible after the milk market organization took effect to prevent an imbalance between butter production and consumption. Even the U.K.'s accession to the EC in 1973 did not bring about a turn in the overall development. Although imports from New Zealand into the new member country were cut from nearly 165,000 to 55,000 tons and although the U.K. turned mainly to France, the Netherlands, and Germany as new supplier countries, the rise of butter prices caused restricted consumption on the English market. In the course of a few years, per capita consumption dropped from 8.8 kg in 1970 to 3.3 kg in 1991 (143).

Between 1977 and 1987, there was an overall decline in the per capita consumption of butter of 16% in 14 European countries, a similar trend was noted in the United States. By 1993, the per capita butter consumption increased in the United States. Price is a strong purchase determinant, and the price of butter has significantly decreased in the United States due to USDA price support policy shifts (89).

A peak in production surplus in the EC was reached in 1986. This was due not only to increasing supplies but also to a notable drop in the consumption of milkfat. The consumer turned to products with a reduced fat content. This trend applies to almost all milk products and has substantially increased the availability of milkfat for butter production (67, 144). Table 16 gives production data for the EU-15 and other countries for butter, dairy spreads, and margarine blends (145).

U.S. prices received for butter by manufacturers, primary receivers, and others at the wholesale level are based primarily on activities on the Chicago Mercantile Exchange (CME). *The Dairy Market News* of the U.S. Department of Agriculture reports Chicago Mercantile Exchange prices, which serve as reference prices for formula pricing of butter (146).

A weekly average price for grade AA butter in July 2004, per the CME was $1.7408 (Carlot) (147).

Spot prices on the exchange, less freight charges to Chicago, are the almost-exclusive basis for prices received at the manufacturing plants for bulk butter. In addition, a manufacturer may receive a premium for uniformity, size of shipment, a special flavor characteristic, or some other characteristic. Manufacturers who sell only bulk butter are generally pricetakers, not pricemakers.

Manufacturers who soft-print and package butter sell it to primary receivers, grocery chains, dairies, and restaurants. Such manufacturers may, depending on competitive conditions, receive a better return than those who sell only bulk.

Primary receivers buy butter from manufacturers at spot prices (plus possible premiums) and sell to several types of customers. Print butter (packaged in pound

TABLE 16. Production of Butter, Dairy Spreads, Margarine, and Blended Spreads.

Country	Years						
EU-15	1990	1991	1994	1995	1996	1997	1998
Austria[a]	35,283	36,131	36,609	36,700	38,600	39,416	39,901
Belgium[b]	55,050	55,050	55,050	33,524	26,130	29,837	30,225
Denmark	28,400	20,100	80,000	80,000	56,080	53,000	53,000
Finland[c]	55,700	51,800	45,300	44,700	46,628	50,000	50,000
France[d]	453,934	411,410	374,813	375,250	406,350	396,477	392,759
Germany	411,300	546,500	558,000	570,000	560,000	577,200	555,000
Greece[d]	2,400	2,400	2,140	1,826	1,514	2,587	2,975
Ireland[e,f]	494	249	254	5	3	3	3
Italy	79,500	80,300	80,300	80,300	80,300	80,300	80,300
Netherlands	177,794	163,304	127,991	131,954	126,094	134,500	149,039
Portugal[f,g]	15,000	15,986	16,300	19,400	19,400	19,400	19,400
Spain	37,500	37,500	27,000	27,000	27,000	27,000	27,000
Sweden[g,h]	20,649	21,211	19,700	16,400	14,500	14,500	14,500
UK	111,000	111,712	115,000	115,000	115,000	115,000	115,000
Total[g,h] (13)	**1,484,004**	**1,553,653**	**1,538,457**	**1,532,059**	**1,517,599**	**1,539,220**	**1,529,102**
Australia	116,470	118,732	142,800	131,417	NA	NA	NA
Brazil[a]	74	70	NA	NA	NA	NA	NA
Czech Republic	119,167	102,870	75,088	77,113	74,515	61,880	65,353
Hungary[j]	38,500	28,911	NA	22,000	NA	NA	NA
Israel[e]	4,000	4,000	NA	NA	NA	NA	NA
Japan[k]	90,900	85,750	NA	NA	NA	NA	NA
Morocco[e]	13,000	13,000	NA	NA	13,000	500	NA
Neth. Antilles	0	0	0	76	0	0	0
Norway	24,069	23,265	NA	13,791	24,433	1,971	NA
Switzerland	42,826	43,442	40,050	41,250	39,290	39,021	40,540
Turkey							

NA = not available.
[a]Revised figures for 1995.
[b]Revised figures.
[c]Revised figures for 1994.
[d]FAO estimate for 1992, 1993.
[e]Estimate for 1993.
[f]Estimate for 1997 and 1998.
[g]Estimate for 1990, FAO figures for 1991, 1992, 1993.
[h]Estimate for 1994–1995–1996.
[i]Estimate for 1990, 1991, 1992.
[j]FAO figures for 1991, 1992, 1993.
[k]Estimate for 1992, 1993.

cartons, usually 4 quarter pounds) is sold to grocery chains and wholesalers who supply retail food stors. Bulk butter is sold to other receivers, butter wholesalers, food processors, and cold storage firms. These sales are based on spot prices plus markup to cover handling, overhead, and profit.

Primary receivers of butter are both pricetakers and pricemakers. Prices they receive (and pay) are based on spot market prices. As many of the primary receivers

are members of the Chicago Mercantile Exchange, they can influence the spot market price by buying and selling butter there. Nonmembers can also buy and sell on the exchange through brokers.

All products sell on a combination of price, perception, and performance. Unfortunately, butter is easily the most expensive of the yellow fats. In terms of perception, all fats are under pressure because of their caloric density. Butter suffers further because it was labeled saturated and has a high-cholesterol content; both properties have been the subjects of adverse comments by the nutritional and medical community. The rise in concern for fat and cholesterol in the U.S. market has overshadowed the concern for chemicals and preservatives.

The flavor and mouth feel of butter are greatly superior to any other yellow fat, but its physical and rheological properties, particularly its poor spreadability at refrigerated temperature, make butter less attractive to many consumers. The margarine and spread industry can tailor its product in terms of spreadability. As noted earlier, many advances in the ability to alter the texture and rheology of butter have been made, but costs tend to deter manufacturers from applying the technologies for marketplace consumption. Apparently, the consumer demand for spreadability characteristics is inhibited by an unwillingness to pay for the convenience. To those who demand a natural food and appreciate its delicate flavor, butter will remain the preferred product.

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