THE EFFECT OF CONDITIONS OF STORAGE ON THE VISCOSITY OF SWEETENED CONDENSED MILK

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The viscosity of sweetened condensed milk increases with age until a gel structure develops. The time required for the milk to change from a fluid to a gel state depends on the quality of the raw milk, the manufacturing processes employed, the composition of the finished milk, and the conditions of storage to which the product is subjected. This paper is concerned with the effect on viscosity of variations in storage conditions, especially the time and temperature of storage.

Sweetened condensed milk should be smooth and free-flowing, but viscous enough to prevent settling of lactose and rise of fat during storage. When age thickening proceeds to the stage of gelation, the milk is no longer suitable for many food uses. Deterioration in flavor generally accompanies the change in viscosity. The data in this report indicate some of the storage conditions that retard undesirable increases in viscosity.

EXPERIMENTAL PROCEDURE

The preparation of laboratory samples of sweetened condensed milk that were uniform in viscosity from batch to batch and from day to day was found to be very difficult. After extensive trials a technique was developed for the processing of 100 lb. of milk of 3.8 per cent fat and 9.15 per cent solids-not-fat, to which was added during concentration 18 lb. of sugar as a boiled sirup. All temperatures were controlled carefully, and the time required to perform each operation was the same for every batch of milk. The milk was forewarmed in a steam-jacketed kettle and concentrated in a 28-inch vacuum pan equipped with a steam jacket for finishing small batches of milk. Cooling and crystallizing were done in a water-jacketed vessel equipped with a stirrer.

Despite the precautions that were taken in preparing laboratory samples, these age thickened more rapidly than did the commercial milks. The laboratory samples were used chiefly in preliminary tests. The results obtained with the experimental milks differed from those with the commercial products in the magnitude of their viscosities, but the relationship between viscosity and the factors being studied was approximately the same in both types of samples.

The commercial sweetened condensed milk was prepared as parts of regular runs in a large condensery in northern New York. Grade A raw

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milk was used, and all manufacturing operations were conducted according to the best factory practice. The finished product was representative of the highest commercial grade of sweetened condensed milk. The condensed milk was shipped from the plant to the Bureau laboratories by express, the trip requiring 5 or 6 days.

The milks were stored in rooms where the temperature was controlled so that fluctuations did not exceed ± 2° F. Samples were not moved or disturbed during storage.

Reliable viscosity determinations on sweetened condensed milk are difficult to make. Stebnitz and Sommer (6) constructed a special viscosimeter utilizing the falling-sphere method. The measurements reported here were made under carefully controlled conditions with a McMichael viscosimeter and standardized wires. The determinations were made at 86° F. in a room maintained at this temperature. Each determination was made with a new sample of milk transferred in the same way and without stirring to the viscosimeter cup. Measurements often were made on duplicate samples and sometimes five or six samples were used to establish a single value. All milk samples either had an initial viscosity or soon developed a viscosity high enough to prevent lactose and fat separation during storage. It is believed that the viscosity values obtained during the work reflect the body condition the consumer would find in the milk. The viscosity is reported in poises but, because of the nature of the material, the values are relative rather than absolute.

Consideration was given to the possibility of bacterial growth during storage of the sweetened condensed milk. Rice and Downs (4) found that most of the organisms that might cause age thickening grew when the sugar ratio was less than 62.5 \( \left( \text{sugar ratio} = \frac{\% \text{ sugar}}{\% \text{ sugar} + \% \text{ water}} \times 100 \right) \) but that growth sometimes occurred up to 64.5. The increase in titratable acidity found by Rice and Downs to accompany bacterial growth was 0.2 to 0.6 per cent after about 30 to 60 days of incubation.

The sugar ratio of the milks used in these experiments was 62.5 to 63.0. The titratable acidity of the samples stored at various temperatures was not always determined, but the tests that were made showed that the acidity of the milks increased about 0.1 per cent during a 3- or 4-month period at the higher temperatures. The age thickening observed in the sweetened condensed milks discussed in this paper was not considered to be influenced significantly by bacterial changes.

RESULTS

Cooling of the product and crystallization of the lactose in sweetened condensed milk may require 2 or 3 hours at temperatures that affect the viscosity of the milk. The effect of the rate of cooling sweetened condensed milk on
its age thickening is shown in table 1. The data represent the average values from five experiments with five different batches of milk. After the concentrates were dropped from the pan, they were cooled to 86 °F in 10 to 15 minutes and seeded. The cooling process of the rapidly cooled samples was continued, but the slowly cooled concentrates were held and stirred at 86 °F for about 2 hours before cooling was continued. The results indicate that the rate of age thickening is substantially the same for both methods of cooling. The lactose crystals in the rapidly cooled milk were a little larger (about 16 μ) in size than the lactose crystals in the slowly cooled milk (about 12 μ).

The relationship between container size and the age thickening of sweetened condensed milk was investigated. The experiments were done on fresh, commercially manufactured samples that were received in the Bureau laboratories in 30-gallon tight oak barrels. Smaller containers in the form of cans of various sizes were filled with sweetened condensed milk. About 3 gallons of milk was taken from the test barrels for this purpose. During the storage period one of the small cans of milk was opened for each viscosity determination.

The milk in the barrels was sampled through the bungs by means of a 1-inch diameter metal tube inserted diagonally from the bung toward one end of the barrel. Care was taken to close the bungs tightly after sampling. Table 2 shows some results of the study of the effect of container size on the viscosity of sweetened condensed milk. The tight oak barrels of sweetened condensed milk were held on the bilge with bungs down.

Two barrels of the milk received in September, 1944, were put in storage at 86 °F. Samples were obtained from one barrel while the other was held unopened until the end of the test. When the sealed barrel was opened at the bung after 76 days, there was insufficient oxygen in the headspace to

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**TABLE 1**

The effect of rate of cooling on age thickening of sweetened condensed milk

<table>
<thead>
<tr>
<th>Storage time at 86° F. (days)</th>
<th>Viscosity after storage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cooled in 162 min. to 63° F. (poises)</td>
</tr>
<tr>
<td>------------------------------</td>
<td>-------------------------</td>
</tr>
<tr>
<td>1</td>
<td>115</td>
</tr>
<tr>
<td>4</td>
<td>204</td>
</tr>
<tr>
<td>12</td>
<td>365</td>
</tr>
<tr>
<td>24</td>
<td>583</td>
</tr>
</tbody>
</table>

*The data represent average values from 2 skim and 3 whole sweetened condensed milks. The samples were made in the Research Laboratory pilot plant during March and April. After condensation, each batch was divided into two parts, one for slow and the other for rapid cooling. The cooled milk was canned and placed at once in a storage room at 86° F.*
support a match flame. The average viscosity of the milk (380 poises) and the titratable acidity (0.55 per cent) were substantially the same as those of the milk in the barrel that had been used for sampling (table 2).

The viscosity of the milk in the barrel that was not opened for sampling was different in various parts of the barrel, after 76 days at 86 °F., being 517 poises at the surface and 478 poises at the bottom. In several places near the center of the barrel the viscosity of the milk was 352 poises. When the barrel was filled by the manufacturer, the temperature of the milk was about 50 °F., and the milk in the center of the barrel probably required appreciable time to warm to 86 °F. In addition, some surface thickening

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**TABLE 2**

**Effect of container size on the viscosity of two lots of sweetened condensed milk of commercial manufacture**

<table>
<thead>
<tr>
<th>Storage time (days)</th>
<th>Barrel (30 gal.) (poises)</th>
<th>No. 3 can (poises)</th>
<th>No. 1 can (poises)</th>
<th>Baby can (poises)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk of September 27, 1943*—storage temperature 70 °F.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 ...........................</td>
<td>69 ...........................</td>
<td>69 ...........................</td>
<td>69 ...........................</td>
<td></td>
</tr>
<tr>
<td>22 ...........................</td>
<td>71 ...........................</td>
<td>71 ...........................</td>
<td>71 ...........................</td>
<td></td>
</tr>
<tr>
<td>40 ...........................</td>
<td>92 ...........................</td>
<td>111 ...........................</td>
<td>115 ...........................</td>
<td></td>
</tr>
<tr>
<td>92 ...........................</td>
<td>148 ...........................</td>
<td>233 ...........................</td>
<td>255 ...........................</td>
<td></td>
</tr>
<tr>
<td>180 ...........................</td>
<td>346 ...........................</td>
<td>446 ...........................</td>
<td>550 ...........................</td>
<td></td>
</tr>
<tr>
<td>256 ...........................</td>
<td>368 ...........................</td>
<td>285 ...........................</td>
<td>346 ...........................</td>
<td></td>
</tr>
<tr>
<td>357 ...........................</td>
<td>382 ...........................</td>
<td>407 ...........................</td>
<td>446 ...........................</td>
<td></td>
</tr>
<tr>
<td>Milk of September 26, 1944†—storage temperature 86 °F.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 ...........................</td>
<td>39 ...........................</td>
<td>39 ...........................</td>
<td>39 ...........................</td>
<td></td>
</tr>
<tr>
<td>8 ...........................</td>
<td>64 ...........................</td>
<td>88 ...........................</td>
<td>86 ...........................</td>
<td></td>
</tr>
<tr>
<td>17 ...........................</td>
<td>80 ...........................</td>
<td>101 ...........................</td>
<td>108 ...........................</td>
<td></td>
</tr>
<tr>
<td>35 ...........................</td>
<td>143 ...........................</td>
<td>168 ...........................</td>
<td>176 ...........................</td>
<td></td>
</tr>
<tr>
<td>74 ...........................</td>
<td>385 ...........................</td>
<td>407 ...........................</td>
<td>429 ...........................</td>
<td></td>
</tr>
</tbody>
</table>

Composition figures furnished by the manufacturer:
* 9.25% fat, 23.0% M.S.N.F., 42.75% sucrose, 25% water.
† 8.73% fat, 23.62% M.S.N.F., 42.75% sucrose, 24.9% water.
Sugar ratio of these milks = 63.

may have been caused when this barrel dried and leaked slightly between the staves. This occurred in the middle of the storage period but the staves tightened up in 3 days when the humidity in the storage room was raised.

The effect of time and temperature of storage upon the viscosity of sweetened condensed milk was investigated. Samples were prepared June 1, 1945, by a cooperating manufacturer as part of a large commercial batch. The samples contained 9.61 per cent fat, 23.91 per cent M.S.N.F., 41.65 per cent sugar, and 24.83 per cent moisture. A barrel of this sweetened condensed milk was shipped to a canning plant, where it was re-packed in special 2-ounce cans on June 8. Four hundred of these small cans were received in these laboratories June 21 and stored at six different tempera-
VISCOSITY OF SWEETENED CONDENSED MILK

Each can held enough milk to make one viscosity determination. Some of the results are plotted in figure 1.

This milk showed a large increase in acidity with age, but apparently this was not caused by bacterial growth. The figures determined on the manufacturer’s milk in six of the 2-ounce cans showed an average standard plate count of 4,380 and a titratable acidity of 0.43 per cent. After 640 days of storage at different temperatures, the titratable acidity and the acid intensity of this milk were: 50°F storage, 0.84 per cent and pH 6.01; 60°F storage, 0.85 per cent and pH 6.09; 72°F storage, 1.0 per cent and pH 5.90. No signs of bacterial growth were found in samples held at these temperatures for 640 days.\(^1\) Anaerobe tubes, direct smears, and standard bacteriological examination of this milk was made by Harold R. Curran of these laboratories.

\(^1\) Bacteriological examination of this milk was made by Harold R. Curran of these laboratories.
plates were practically negative. While it was not shown that growth of organisms was absent during the whole storage period, the available evidence indicates that the acidity increase was due to chemical changes rather than to bacterial activity.

The storage temperature of a group of the 2-ounce cans of sweetened condensed milk was varied from 60° F. to 98° F. by shifting the cans every 24 hours from one temperature to the other. The initial viscosity of the milk was 132 poises, but after storage for 170 days a soft gel had formed with a viscosity of 1,155 poises. By reference to figure 1 it may be determined that this is the viscosity the milk would have reached if it had been held 170 days at a constant temperature of 89° F.

Sweetened condensed milks that were stored for several months at 0° F. did not show important physical changes. There was no measurable change in viscosity and no apparent change in the dispersion of the protein or the fat. There was no protein flaking or insolvency, such as occurs in frozen unsweetened milk. There was an increase in the size of lactose crystals in sweetened condensed milks held at 0° F. only when the lactose was incompletely crystallized as a result of improper cooling during the manufacturing process.

DISCUSSION

The keeping quality of sweetened condensed milk is closely associated with its viscosity. Whenever sweetened condensed milk age thickened to a viscosity of 600 to 800 poises, it generally was no longer suitable for use in high-grade food products. Off flavors often developed and the milk was too viscous to handle easily. A soft gel structure was present at 1,000 poises. The gel could be reduced by stirring, but it re-formed when the milk remained undisturbed.

The viscosity of sweetened condensed milk increased at about the same rate during the cooling and crystallization periods as it did during storage under the same conditions of temperature.

The data of table 2 indicate that sweetened condensed milk packed in barrels will remain fluid a little longer than milk packed in cans when both are held under the same conditions of storage. The temperature of milk in cans follows fluctuations in storage temperature more closely than does the temperature of milk in barrels. Commercial experience indicates that the sweetened condensed milk in the middle of a 50-gallon barrel will require about 7 days to reach 85° F. after previous storage at about 60° F. (1). A longer time is required for the reverse change to take place. Cool milk packed in barrels will remain cool and thin longer after the container is placed at a high temperature than will milk in small cans.

These considerations, and the fact that high sugar concentrations stabilize the milk and retard viscosity changes, support the suggestion (2)
that bulk sweetened condensed milk may have a minimum sugar ratio of 60, while the sugar ratio of the canned milk should be at least 62.5. However, a bulk sweetened condensed milk with a sugar ratio of 62.5 will be superior to one that contains less sugar.

Data from the curves of figure 1 were used to prepare figure 2, in which the logarithms of the viscosities are plotted against the temperatures of storage.

Fig. 2. The effect of time and temperature of storage on the viscosity of sweetened condensed milk. Data taken from figure 1.

The time required for the sweetened condensed milk to reach a viscosity of 600 poises at different temperatures is indicated in figure 1. When these temperature data were plotted against the logarithms of the time of storage, straight line no. 1, figure 3, was obtained. Values for 30, 40, and 50 °F., obtained by extrapolation of curve no. 1, figure 3, are 4,950, 2,460, and 1,225 days, respectively. Other data also are plotted on figure 3.
If $n =$ viscosity and $c, c', c'' =$ constants, the relationship shown in figure 1 may be expressed as follows: $n = c'$ (time of storage) or $\log n = c''$ (log time), while for figure 2 $\log n = c$ (temperature of storage); then $c$ (temperature) $= c''$ (log time), the relationship shown in figure 3 where the viscosity is constant.

The data given in figure 1 and re-plotted in figures 2 and 3 show that

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**Fig. 3.** The relationship between the time and temperature of storage in the development of viscosity of sweetened condensed milk: Curve 1, data from figure 1, viscosity of 600 poises. Curve 2, data from table 2, viscosity of 300 poises. The points for 70° F. and for 86° F. were obtained with different milks stored in baby-size cans. Curve 3, data from table 2, viscosity equals 300 poises. The points for 70° F. and for 86° F. were obtained with different milks stored in barrels. Curve 4, data from Rogers *et al.* (5), viscosity of 12° rotation on special viscosimeter. Curve 5, data from Leighton and Mudge (3) in which the time is given in hours (not days) required for the milk to start thickening.
the viscosity of sweetened condensed milk increases arithmetically with time of storage but logarithmically with temperature of storage. For conditions of constant viscosity the time of storage varies logarithmically with the temperature of storage.

Although the logarithms of the storage times required for a sweetened condensed milk to reach a certain viscosity, plotted against the temperatures of storage, yield a straight line (fig. 3), the slope of this line may vary with different milks. The milk used by Leighton and Mudge (3), figure 3, gave a line of different slope from that of the other milks. The data of Leighton and Mudge were obtained by observing the number of hours required for the milk to start thickening. It seems probable that most commercial milks will thicken much as did milk no. 1 of figure 3. It should be possible to estimate the length of time a sweetened condensed milk will retain a satisfactory viscosity at various storage temperatures by using the data of figure 3. The rate of thickening approximately doubles with each increase of 10°F. between 30 and 60°F.

In some cases the slope of the time-temperature curve of a milk may differ from that of curve 1, figure 3. A line may be drawn for any milk if two points are obtained. To secure these points quickly, about six samples of a milk may be held at each of two high temperatures such as 98°F and 120°F. Viscosity determinations should be made at 1- or 2-day intervals and curves drawn like those of figure 1. Two points having the same viscosity value then may be used to construct a time-temperature curve patterned after that of figure 3. Other points may be taken from the curve or they may be calculated from the geometric equation for a straight line. The equation may be stated in the following form:

\[
\frac{\log y - \log y_1}{\log y_2 - \log y_1} = \frac{x - x_1}{x_2 - x_1}
\]

when

\[ y = \text{storage time} \]
\[ x = \text{storage temperature} \]
\[ y_1 \text{ and } y_2 = \text{storage times at } x_1 \text{ and } x_2 \text{ storage temperatures.} \]

For a milk similar to that shown in curve 1, figure 3, the storage time \( y \) required to reach a viscosity of 600 poises at a given temperature \( x \) may be found from the equation calculated from the plot:

\[
\log y = 4.64 - \frac{1.82 x}{59}
\]

It is important to note that the time-temperature relationship of figure 3 will hold only when the storage temperature is constant. If the storage temperature fluctuates, the changes in viscosity will be dependent upon the extent of the changes.

The theoretical freezing point of sweetened condensed milk is about 5°F., but only a few ice crystals form at this temperature. Since all the
moisture in sweetened condensed milk will freeze only at a much lower temperature, neither the milk nor the container is damaged by storage at temperatures considerably below 0° F. Sweetened condensed milk that was held at 0° F. for many months did not change measurably in viscosity. Extrapolation of Curve 1, figure 3, indicates that 24,000 days (65 years) at 0° F. would be required for this milk to reach a viscosity of 600 poises.

**SUMMARY**

The viscosities of sweetened condensed milks held in the same storage room increased a little more rapidly in the milks packed in small cans than they did in the milks packed in barrels.

The viscosity of sweetened condensed milk increased logarithmically with increases in storage temperature and arithmetically with increases in storage time. For conditions of constant viscosity, time varied logarithmically with temperature. Viscosity values may be predicted by applying this relationship to time-temperature data from high temperature, accelerated storage tests.

The viscosity of sweetened condensed milk increased at about the same rate during the cooling and crystallization periods as it did during storage under identical conditions of time and temperature.

The authors wish to express their appreciation to P. L. Haymes, H. D. Wilder, and A. R. Davis, of the United Milk Products Company, for their numerous suggestions and their active interest in this project and for their manufacture of the commercial samples of sweetened condensed milk.

**REFERENCES**

(1) Haymes, P. L. Cleveland, Ohio. Information received March, 1947.

(2) Hunziker, O. F. LaGrange, Ill. Information by correspondence, April, 1947.


