

Estimating Creaming Rates For Homogenized Milk

Since the introduction of homogenized milk, there has been a need to know the size of the homogenized fat globules. This information helps in understanding the efficiency of the homogenizer and the relationship of globule droplet size to the rate of creaming of milk. One of the first standards proposed for a creaming test in the United States was called the U.S. Public Health Service Index of Homogenized Milk (Top and Bottom Test.) This test involves removing the top 100 mL of milk from a one-quart milk sample that has been sitting for 48 hours at a temperature between 40 and 50 F (4 to 8 C). The percentage of fat in the remaining (bottom) portion of the milk sample is subtracted from the percentage of fat in the top portion, and this difference is divided by the percentage of fat in the top portion all times 100. The index should be less than 10 percent. However, this top and bottom test was introduced in about 1947 when homogenizing pressures typically were higher than those used today. Also, the requirement to remove the top portion was not easily performed and much error could be introduced into the test.

In the early 1980s, APV Gaulin introduced the EQA™ Analyzer to check for homogenization efficiency. This instrument measures the amount of light passing through a diluted milk sample. Using laws of light scattering and spectroturbidity, the EQA Analyzer converts the amount of light transmitted through a diluted milk sample to a mean diameter (d_{43}) for the milk emulsion. The d_{43} mean diameter is a measure of the creaming rate for the milk because it encompasses an aspect of the size distribution.

The d_{43} is defined as:

$$d_{43} = \frac{\sum N_i d_i^4}{\sum N_i d_i^3} \quad (1)$$

Where N_i is the number of droplets in class size i and d_i is the diameter of the droplets in class size i .

Although dairies use the EQA Analyzer as a method to monitor homogenization quality, the relationship of mean diameter to creaming rate and code date is not always apparent. Clearly, a connection between the d_{43} and code date needs to be established.

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The processor determines the code date or sell-by date. "Shelf-life' is defined as the length of time that a food can be held under recommended or practical storage conditions and still maintain its 'freshness' or acceptable quality. The anticipated shelf-life of milk is reflected in its 'sell-by' or 'code-date,' while many products remain fresh for a period after this date...The average shelf-life of pasteurized milk held under proper refrigeration, defined as less than 45°F, is 12 – 16 days...The average shelf-life of Ultra-Pasteurized milk products is 30 – 90 days when held under refrigeration..." (*Dairy Science Facts*, Cornell University, College of Agriculture and Life Sciences, 2000.)

A description is given in published literature about the creaming rate in homogenized milk. (P. Walstra and H. Oortwijn, "Effect of globule size and concentration on creaming in pasteurized milk," *Neth. Milk Dairy J*, **29** (1975), pp. 263 – 278, and H. Mulder and P. Walstra, *The milk fat globule: emulsion science as applied to milk products and comparable foods*: Pudoc, Wageningen & CAB, Farnham Royal, 1974, pp. 139 – 143.)

The following derivation is based on these published papers. Stoke's law can characterize creaming in an emulsion. The equation is given as:

$$v_s = a(\rho_g - \rho_p) d^2 / 18\eta \quad (2)$$

Where v_s is the terminal velocity of the globule; a is the gravitational constant (9.81 m/s^2); ρ_g is the mass density of the globule; ρ_p is the mass density of milk plasma; d is the globule diameter and η is the viscosity of the milk plasma. Because the globule is less dense than the plasma, the sign of the equation is negative but this is understood and is omitted (particles rising rather than settling.)

It is possible to take Stoke's law and add equations for the total fat volume or mass and the volume-weighted size distribution. The references should be consulted for the complete derivations. This leads to the following equation:

$$R = a(\rho_g - \rho_p) Ht / 18 \eta h \quad (3)$$

Where R is the proportion of fat that has creamed ($1 - [\text{fat content of separated milk}/\text{fat content of milk}]$); H is a creaming parameter with units of μm^2 and h is the "creaming depth or maximum distance to be covered by rising globules before reaching the cream layer."

The creaming parameter H is defined as:

$$H = \frac{\sum N_i d_i^5}{\sum N_i d_i^3} \quad (4)$$

After inserting constants and making unit conversions, the following equation is derived:

$$CR = \frac{4.7(\rho_p - \rho_g)H}{\eta h} \quad (5)$$

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Where CR is the creaming rate in percent per day, and h is the height of the vessel containing the milk sample in cm. The viscosity of the plasma, η , is in poise which equals g/cm-s.

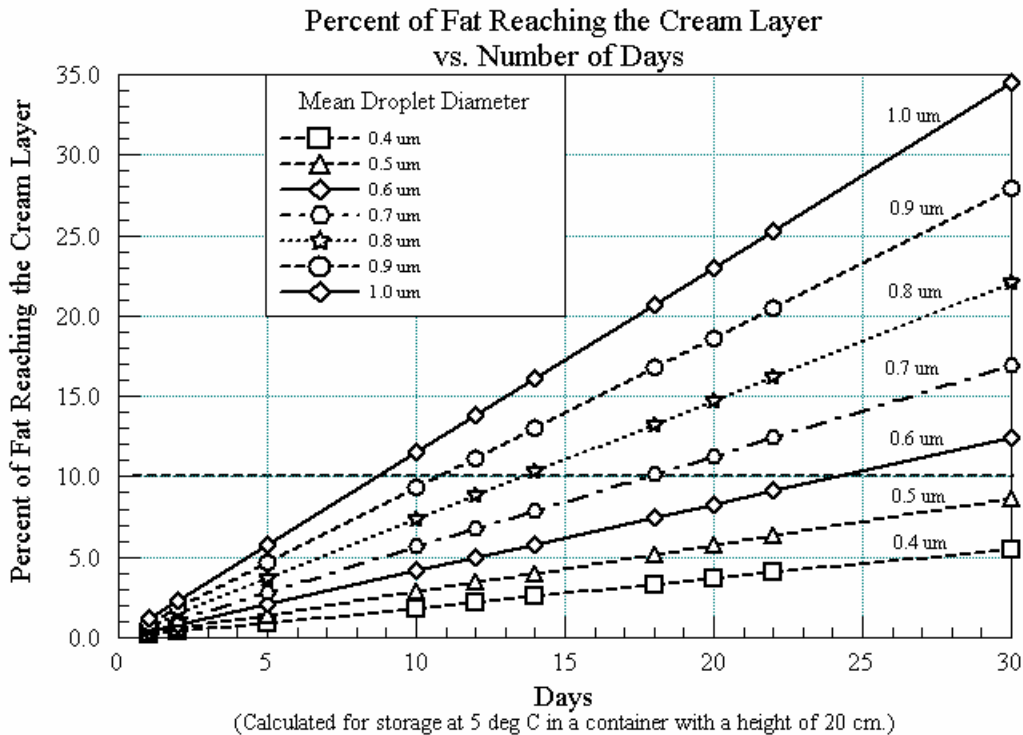
The references above give values for density and viscosity at different temperatures. Also, the creaming parameter can be related to the d_{43} by the approximation of

$$H \approx 1.8 (d_{43})^2 \tag{6}$$

(P. Walstra, *Effect of homogenization on the fat globule size distribution in milk*, Neth. Milk Dairy J. **29** (1975), pp. 279 – 294.)

One can now relate the mean diameter, d_{43} , as measured by the EQA Analyzer to estimate the rate of creaming for homogenized milk. Of course, there are a number of conditions to the application of Stoke's law such as the globules should be perfect spheres; the globules should be homogeneous spheres; the liquid should be Newtonian; there should be no interaction between globules; Brownian motion should be small compared to the displacement by creaming; plus other conditions. However, even taking into account these conditions, Stoke's law can be used as an approximation for the creaming rate.

Using equation 5 and 6 and the physical parameters provided in the references, one can calculate a creaming rate. For the calculation, a vessel with a height of 20 cm and a storage temperature of 5° C (41° F) were selected. A graph can now be constructed showing the creaming rate versus number of days of storage.



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Now, we know from over 20 years of experience with the Micro-Gap® homogenizing valve (U.S. Patents 5,749,650 and 5,899,564) that for a code date of 11 to 12 days after packaging, an EQA Analyzer mean diameter of 0.8 – 0.85 µm is adequate to avoid significant creaming. If a line is drawn at 10% creaming, then the d₄₃ of 0.8 – 0.85 µm falls below this line at 12 days. For a code date of 16 days, the d₄₃ should be about 0.7 µm. For 18 to 20 days, the d₄₃ should be about 0.6 µm, etc. The graph makes sense because for extended shelf life (ESL) milk with a code date of 30 days analysis of this type of sample suggests a d₄₃ of about 0.5 µm. Of course, the assumption is that the creaming is only affected by the diameter and size distribution of the fat globules. Any other product defect such as entrained air, damaged protein or a mix of unhomogenized and homogenized milk is not accounted for.

Another way to express this data is with the following equation:

$$d_{43} = \sqrt{\frac{7.83}{Days}} \quad (7)$$

This calculation sets the upper limit of the creaming rate to 9% to be certain that there is a safety factor in the selection of the mean diameter. Using this approximation, it is possible to suggest some homogenizing pressures to achieve these results.

Code Date	d ₄₃ Micrometers	Conventional Valve Pressure/psi (bar)	Micro-Gap Valve Pressure/psi (bar)
10 – 12 Days	0.88 – 0.80	1800 – 2000 (124 – 138)	1200 – 1400 (83 – 97)
13 – 15 Days	0.78 – 0.72	2000 – 2400 (138 – 165)	1400 – 1600 (97 – 110)
16 – 20 Days	0.70 – 0.63	2400 – 2700 (165 – 186)	1600 – 1800 (110 – 124)
21 – 30 Days	0.61 – 0.51	3000 – 4500 (207 – 310)	2000 – 3200 (138 – 221)

NOTE:

- 1) The actual required pressure depends on the condition of the homogenizing valve, style of valve, flow rate and processing system configuration.
- 2) Obtaining these mean diameters does not mean that no creaming will occur. However, with these homogenization conditions, creaming will be slight, and most of the surface cream can be mixed back into the milk with normal agitation of the container.
- 3) The EQA Analyzer is designed to measure the mean diameter of a properly homogenized sample. If the milk sample contains a portion of unhomogenized milk, the EQA Analyzer may or may not indicate its presence. This is because the oversized globules may be small in number and outside the range of sensitivity of the instrument. A large percentage of unhomogenized milk in the sample will result in a false reading.

W.D. Pandolfe 24 January 2005

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Phone: 1-888-278-4321 Email: answers.us@apv.com

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