Freezing Point Depression of a Mix

To calculate the freezing point of a given mix, the first step is to determine the equivalent content of sucrose in the mix, based on all the mono- and disaccharides that are present. This is referred to as the sucrose equivalence (SE) in g/100g of mix.

SE = (NMS x 0.545) + (WS x 0.765) + S + (10DE CSS x 0.2) + (36DE CSS x 0.6) + (42DE CSS x 0.8) + (62DE CSS x 1.2) + (HFCS x 1.8) + (F x 1.9)

Where**:**

NMS = nonfat milk solids, 0.545 is the percentage of lactose typical of NMS**;**
WS = whey solids (from dry or condensed whey), 0.765 is the percentage of lactose typically found in whey solids**;**
S = sucrose or other disaccharides such as lactose or maltose added directly**;**
DE = dextrose equivalence of the CSS (corn syrup solids);
HFCS = high fructose corn syrup**;**
F = pure fructose or other pure monosaccharides such as dextrose**;**
all in g/100g mix (or %).

If blended protein, lactose and mineral ingredients are used as a source of NMS, the lactose and salts in those ingredients should be included directly in the calculation rather than using the factors for NMS or WP. Simply ensure that all lactose and salts are accounted for and none are double-counted.

The equivalent concentration of sucrose in water (g/100g water) is then determined by dividing the SE by the water content.

g sucrose/100g water = SE x 100/W

where: W is the water content (100 – total solids, %).

To obtain the freezing point depression associated with this concentration of SE in water, FPD_{SE}, the table below is used.

The contribution to freezing point depression from salts in NMS and WS is found using the following equation:

$$FPD_{SA} = \frac{(NMS + WS) \times 2.37}{W}$$

Here, FPD_{SA} is the freezing point depression for salts (°C) contained in NMS and WS, and the constant 2.37 is based on the average molecular weight and concentration of the salts present in milk. For computation in °F, the factor 4.26 is used. To obtain the freezing point depression of the ice cream mix, FPD_T, the two contributions are summed.

$$FPD_T = FPD_{SE} + FPD_{SA}$$

Freezing point depression (°C) below 0°C of sucrose solutions (g/100g water). Data were extrapolated from Leighton (1927), which were originally derived from Pickering (1891).

g Sucrose / 100 g water	FPD (°C)	g Sucrose / 100 g water	FPD (°C)	g Sucrose / 100 g water	FPD (°C)
3	0.18	63	4.10	123	9.19
6	0.35	66	4.33	126	9.45
9	0.53	69	4.54	129	9.71
12	0.72	72	4.77	132	9.96
15	0.90	75	5.00	135	10.22
18	1.10	78	5.26	138	10.47
21	1.29	81	5.53	141	10.72
24	1.47	84	5.77	144	10.97
27	1.67	87	5.99	147	11.19
30	1.86	90	6.23	150	11.41
33	2.03	93	6.50	153	11.63
36	2.21	96	6.80	156	11.88
39	2.40	99	7.04	159	12.14
42	2.60	102	7.32	162	12.40
45	2.78	105	7.56	165	12.67
48	2.99	108	7.80	168	12.88
51	3.20	111	8.04	171	13.08
54	3.42	114	8.33	174	13.28
57	3.63	117	8.62	177	13.48
60	3.85	120	8.92	180	13.68

Example Problem.

Calculate the initial freezing point of an ice cream mix containing 10% NMS, 2% whey solids, 12% sucrose, 4% 42DE CSS, and 60% water (40% total solids).

First, calculate the sucrose equivalents:

SE = (10 x 0.545) + (2 x 0.765) + 12 + (4 x 0.8) = 22.18

The equivalent concentration of sucrose in water is,

g sucrose/100g water = 22.18 x 100/60 = 36.97

Now, by interpolation find the freezing point depression for this level of sucrose equivalent from the table.

FPD_{SE} = 2.27°

For salts:

FPD_{SA} = (10 + 2) x 2.37 = 0.47°

Find the total freezing point depression for the mix:

FPD_T = 2.27° + 0.47° = 2.74°

Thus, the initial freezing point temperature for this ice cream mix is –2.74°C.

Freezing Curves

The initial freezing point can then be used to compute a freezing curve, where the percent of water frozen in the mix (removed as ice) is plotted against freezing temperature. This is done by continually reducing the water content (W) in the mix and recalculating the FPDT as above, since the remainder of the water is converted to ice and no longer acting as a solution.

Example Problem.
Calculate the freezing curve for ice cream, based on a mix containing 10% NMS, 2% whey solids, 12% sucrose, 4% 42DE CSS, and 60% water (40% total solids).

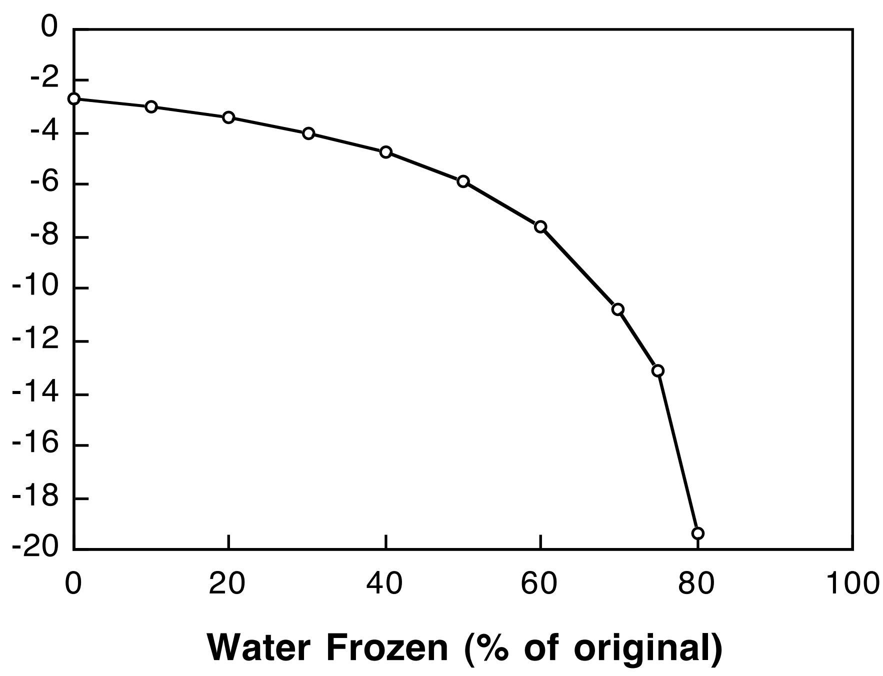
From above, we calculated that the initial freezing point (0% water frozen) was –2.74°C. When 20% of the water is frozen, 80% is still liquid, so W is now (60% x 0.8) = 48%. The g sucrose/100g water is now 22.18 x 100/48 or 46.21g/100g water. From Table 5.1, this (FPDSE) corresponds to 2.86°C. For the milk salts, FPDSA = (10 + 2) x 2.37/48 = 0.59°C. Thus, FPDT = 2.86° + 0.59° = 3.45°C. At –3.45°C, we conclude that 20% of the water in this mix will be frozen.

Similarly, a series of ice contents can be used, sufficient to plot a freezing curve. Such values are shown in the following table and plotted in the following figure.

Freezing Point Depression Values[1] Applicable to the Formula in the above example problem when 10 to 80% of the water in the ice cream is frozen.

% water frozen	W	g sucrose/100g water	FPD_{SE}	FPD_{SA}	FPD_T
10	54	41.07	2.53	0.53	3.06
20	48	46.21	2.86	0.59	3.45
30	42	52.81	3.33	0.68	4.01
40	36	61.61	3.97	0.79	4.76
50	30	73.93	4.92	0.95	5.87
60	24	92.42	6.45	1.18	7.63
70	18	123.22	9.21	1.58	10.79
75	15	147.87	11.26	1.90	13.16
80	12	184.83	14.27	2.37	16.61

[1] FPD_{SE} = freezing point depression of sucrose equivalents
FPD_{SA} = freezing point depression of salts
FPD_T = total freezing point depression



Freezing point depression curve for a mix with 10% NMS, 2% whey solids, 12% sucrose, 4% 42DE CSS, and 60% water (40% total solids).