Grain Utilization

Equations

$$G = k(\frac{G_t M}{V_r})$$

$$M = \frac{V_r G}{G_t k}$$

- G = Contribution of grain to Starting Gravity (for example, 50)
- k - Mash efficiency (for example, 0.75)
- G_t = Gravity of grain at 100% efficiency = 46.2 (DBFB Extract - MC - 0.002)
- M = Amount of grain (pounds)
- V_r = Batch size (gallons)

Tables

Table 1: Table of grains, theoretical gravity, and color

Grain	G_t	**°SRM**
Flaked Maize	40.0	1.0
Flaked Rice	40.0	1.0
English 2-row lager	38.0	1.4
American Cara-Pils / Dextrine	33.0	1.5
German 2-row Pils	38.0	1.6
Belgian wheat	38.0	1.8
American 2-row	37.0	1.8
American Klages 2-row	37.0	1.8
German wheat	39.0	1.6
English 2-row Pils	36.0	1.8
Briess 6-row	34.0	1.8
Midwest wheat	37.0	2.0
Honey	35.0	2.0
Flaked Wheat	34.0	2.0
Flaked Oats	33.0	2.0
Flaked Barley	32.0	2.0
English wheat	37.0	2.2
German light crystal	37.0	2.5

... continued on next page

Table 1: Table of grains, theoretical gravity, and color (... continued)

Grain	G_t	**°SRM**
German Vienna	37.0	2.7
Dingemans Pilsner	35.0	2.9
Dingemans Pale	35.0	3.0
Wheat Malt Extract Syrup	37.0	3.0
English mild	37.0	3.5
English 2-row Vienna	36.0	3.5
Briess Rye Malt	33.0	3.7
Pacific Northwest wheat	40.0	4.0
American Vienna	35.0	4.0
Crisp Maris Otter	37.0	4.0
Light Malt Extract Syrup	37.0	5.0
English 2-row Munich	37.0	6.0
Smoked American 2-row	36.0	7.0
Light Dried Malt Extract	45.0	7.5
Belgian Munich	38.0	7.8
Belgian Cara-Pils	34.0	7.8
German Munich	37.0	8.9
German Smoked (Rauchmalt)	37.0	9.0
Amber Malt Extract Syrup	36.0	9.0
American crystal 10L	35.0	10.0
American Munich 10L	34.0	10.0
Amber Dried Malt Extract	45.0	12.5
Dark Malt Extract Syrup	36.0	15.0
Dark Dried Malt Extract	44.0	18.0
American crystal 20L	35.0	20.0
Belgian Caravienne	34.0	22.0
Belgian Biscuit	35.0	23.0
English carastan	35.0	23.5
German crystal 25L	37.0	25.0
American Victory	34.0	25.0
Belgian Aromatic	36.0	26.0
American Munich 30L	34.0	30.0
American crystal 40L	34.0	40.0
American crystal 60L	34.0	60.0
English Brown / Amber	32.0	65.0

... continued on next page

Table 1: Table of grains, theoretical gravity, and color (... continued)

Grain	G_t	**°SRM**
Belgian caramel Munich	33.0	72.0
German crystal 75L	37.0	75.0
American crystal 80L	34.0	80.0
German crystal 95L	36.0	95.0
American crystal 120L	33.0	120.0
English crystal	35.0	125.0
Belgian Special B	30.0	221.0
Breiss Roasted Barley	25.0	300.0
American Chocolate	25.0	350.0
English Chocolate	34.0	475.0
Belgian Chocolate	30.0	500.0
American Blank Patent	25.0	500.0
English Blank Patent	26.0	525.0
Black Roasted Barley	25.0	525.0
Belgian Blank Patent	30.0	600.0

Cereal Mash

Steps

1. Mill grains to the consistency of grits.
2. Add 8 ounces of milled 2- or 6-row malted barley.
3. Add water at a ration of 3 quarts / pound.
4. Raise mash to mashing temperature (see chart below) and let rest for 15 minutes.
5. Bring the mash to a gentle boil for 20–30 minutes.
6. Add cereal mash to main mash.

Tables

Table 2: Table of cereal grain gelatinization temperatures

Grain	**Temperature range (°F)**
Barley	140–150

... continued on next page

Table 2: Table of cereal grain gelatinization temperatures (... continued)

Grain	Temperature range (°F)
Wheat	136–147
Rye	135–158
Oats	127–138
Maize	143–165
Rice	154–172

Color Equations

Equations

Malt Color Unit equation:

$$\textbf{MCU} = \frac{C_t M}{V_r}$$

°SRM Conversion equation (valid for $0 \leq \textbf{MCU} \leq 150$):

$$\textbf{°SRM} = 0.337\textbf{MCU} - 0.000954\textbf{MCU}^2 + 4.50 \log_{10}(\textbf{MCU} + 1)$$

- **MCU** = Contribution of grain to Malt Color Units
- **°SRM** = Color of finished beer
- C_t = Malt color (**°SRM**/**°L**)
- M = Amount of grain (pounds)
- V_r = Batch size (gallons)

Tables

Table 3: Malt Color Units to °SRM Conversion Table

MCU	°SRM	MCU	°SRM	MCU	°SRM
0	0	52	22	104	33
2	2	54	23	106	34
4	4	56	23	108	34
6	5	58	24	110	34
8	6	60	24	112	35
10	7	62	25	114	35
12	8	64	25	116	35

... continued on next page

Table 3: Malt Color Units to °SRM Conversion Table (... continued)

MCU	°SRM	MCU	°SRM	MCU	°SRM
14	9	66	26	118	35
16	10	68	26	120	36
18	11	70	27	122	36
20	12	72	27	124	36
22	13	74	28	126	36
24	13	76	28	128	37
26	14	78	29	130	37
28	15	80	29	132	37
30	15	82	29	134	37
32	16	84	30	136	37
34	17	86	30	138	37
36	17	88	31	140	38
38	18	90	31	142	38
40	19	92	31	144	38
42	19	94	32	146	38
44	20	96	32	148	38
46	21	98	32	150	38
48	21	100	33	152	39
50	22	102	33	154	39

Water Chemistry

Equations

$$\frac{559h}{w} = a - 5.6l - 0.7c - 0.6m + 50$$

Table 4: Water chemistry varibles and equations

Parameter	Variable	Equation
Ca^2 (ppm)	c	$c =$ base Ca^2 + salt additions from above table.
Mg^2 (ppm)	m	$m =$ base Mg^2 + salt additions from above table.
HCO_3^- (ppm)	b	$b =$ base HCO_3^- + salt additions (if any).

... continued on next page

Table 4: Water chemistry varibles and equations (... continued)

Parameter	Variable	Equation
Brewing water (quarts)	w	
Beer color (°SRM)	l	
Alkalinity (ppm $CaCO_3$)	a	$a = 0.82b$ (or from water analysis)
Residual Alkalinity (ppm $CaCO_3$)	r	$r = a - 0.7c - 0.6m$ (116.5 for Fairbanks)
Desired Residual Alkalinity	d	$d = 5.6l - 50$
Lactic Acid, 88% (ml)	h	$h = w(r - d)/559$
Mash pH	p	$p = 5.7 + 0.00168a - 0.0012c - 0.000982m$

Mash pH is measured at room temperature, assumes an all pale malt mash, and doesn't include any acid additions (h).

Tables

Table 5: Salts for Water Adjustment

Salt (1 gram / quart)	Concentration	Mash effect	Comments
$CaSO_4$ (Gypsum)	244 ppm Ca^2, 588 ppm SO_4^{-2}, 4.4 g/t	Lower pH	
$CaCl_2$	288 ppm Ca^2, 508 ppm Cl^-	Lower pH	
$MgSO_4$ (Epsom Salt)	104 ppm Mg^2, 412 ppm SO_4^{-2}	Lower pH	Minor effect
$CaCO_3$ (Chalk)	420 ppm Ca^2, 632 ppm CO_2^{-2}	Raise pH	Add to mash
$NaHCO_3$ (Baking soda)	300 ppm Na–, 764 ppm HCO_3^-, 4.9 g/t	Raise pH	
NaCl (Canning salt)	416 ppm Na–, 640 ppm Cl^-, 12.3 g/t		

Table 6: Ion concentrations in classic brewing cities

City	Classic Style	HCO_3^-	Ca^2	Mg^2	$Na^–$	SO_4^{-2}	Cl^-	Alk.
Burton	Pale Ale, Bitter	141	268	62	30	638	36	116
Dortmund	Weizen	221	225	40	60	120	60	181
Dublin	Dry Stout	319	118	4	12	54	19	262
Edinburgh	Scottish Ale	270	140	36	92	231	60	221
London	Mild, Brown, Porter	123	90	4	24	58	18	101
	Sweet Stout	160	50	20	100	80	60	131
Munich	Dark Lager	148	75	18	2	10	2	121
Pilsen	Pale Lager	14	7	2	2	5	5	11
Vienna	Märzen	118	200	60	8	125	12	97
Yorkshire	Malty Ale	153	105	17	23	66	30	126
Fairbanks (2004)	Brown Ale, Porter	150	38	13	7	5	11	123
Fairbanks (2006)	Brown Ale, Porter	182	37	11	17	20	17	149
Fox (2004)	Porter, Stout	214	60	18	4	16	0	176
Fox (2006)	Porter, Stout	221	59	17	4	14	0	181
Pioneer Wells		224	4	0	111	8	0	184

Mash & Sparge Infusion

Equations

Table 7: Conversions

Volume of 1 pound grain	0.125 gallons ~ ½ quart
Maximum amount of grain in a 10 gallon tun	1.0 q/#: 26.7#, 1.2 q/#: 23.5#, 1.5 q/#: 20#
Heat capacity of 1 pound grain	0.8 × heat capacity of 1 quart of water

Initial infusion equations:

Traditional thermodynamics equations:

$$T_a = \frac{T_t\Big(C_m M + C_w(8.35W_a/4)\Big) - C_m M \times T_i}{C_w(8.35W_a/4)} + T_m$$

$$T_a = \frac{T_t(0.4M + 2.09W_a) - 0.4M \times T_i}{2.09W_a} + T_m$$

Palmer, *How to Brew*

$$T_a = \left[\frac{0.2}{r}(T_t - T_i)\right] + T_t + T_m$$

Mash infusion equations:

$$(C_M M + C_w(8.35W_m/4))(T_t - T_i) = C_w(8.35W_a/4)(T_a - T_t)$$

$$(0.4M + 2.09W_m)(T_t - T_i) = 2.09W_a(T_a - T_t)$$

$$W_a = \frac{(T_t - T_i)(0.4M + 2.09W_m)}{2.09(T_a - T_t)}$$

$$T_a = \frac{(T_t - T_i)(0.4M + 2.09W_m)}{2.09W_a} + T_t + T_m$$

$$T_t = \frac{2.09T_aW_a + T_i(0.4M + 2.09W_m)}{2.09W_a + 0.4M + 2.09W_m}$$

Variables

- T_a = Infusion water temperature (°F)
- r = Mash ratio (quarts / pound)
- T_t = Target temperature (°F)
- T_i = Initial temperature (°F)
- W_a = Heated water to add (quarts)
- W_m = Water already in the mash (quarts)
- M = Amount of grain (pounds)

Calculation Coefficients

- C_m = Heat capacity of grains (~0.35)
- C_w = Heat capacity of water (1.0)
- T_m = Temperature lost to mash tun (°F)

Tables

Table 8: Initial Infusion Water Temperature (°F)

Target Temp (°F)	Grist Ratio (q/#)							
	0.8	**0.9**	**1.0**	**1.1**	**1.2**	**1.3**	**1.4**	**1.5**
148	165	163	162	161	160	159	158	157
149	167	165	163	162	161	160	159	158
150	168	166	164	163	162	161	160	159
151	169	167	165	164	163	162	161	161
152	170	168	167	165	164	163	162	162
153	171	169	168	166	165	164	164	163
154	173	171	169	168	166	165	165	164
155	174	172	170	169	168	167	166	165
156	175	173	171	170	169	168	167	166
157	176	174	172	171	170	169	168	167
158	177	175	174	172	171	170	169	168

Table 9: No-Sparge Infusion Volume (quarts) @ Temperature (°F), Grist Ratio of 1.0 q/#

Grain (#)	Grist Temperature (°F)					
	148	**149**	**150**	**151**	**152**	**153**
8	28.0 @ 175	28.0 @ 174	28.0 @ 174	28.0 @ 174	28.0 @ 173	28.0 @ 173
9	27.5 @ 176	27.5 @ 175	27.5 @ 175	27.5 @ 174	27.5 @ 174	27.5 @ 174
10	27.0 @ 177	27.0 @ 176	27.0 @ 176	27.0 @ 175	27.0 @ 175	27.0 @ 174
11	26.5 @ 178	26.5 @ 177	26.5 @ 177	26.5 @ 176	26.5 @ 176	26.5 @ 175
12	26.0 @ 179	26.0 @ 178	26.0 @ 178	26.0 @ 177	26.0 @ 177	26.0 @ 176
13	26.0 @ 180	26.0 @ 179	26.0 @ 179	26.0 @ 178	26.0 @ 177	26.0 @ 177
14	25.5 @ 181	25.5 @ 180	25.5 @ 180	25.5 @ 179	25.5 @ 178	25.5 @ 178
	154	**155**	**156**	**157**	**158**	
8	28.0 @ 173	28.0 @ 172	28.0 @ 172	28.0 @ 172	28.0 @ 171	
9	27.5 @ 173	27.5 @ 173	27.5 @ 173	27.5 @ 172	27.5 @ 172	
10	27.0 @ 174	27.0 @ 174	27.0 @ 173	27.0 @ 173	27.0 @ 172	
11	26.5 @ 175	26.5 @ 174	26.5 @ 174	26.5 @ 173	26.5 @ 173	
12	26.0 @ 176	26.0 @ 175	26.0 @ 174	26.0 @ 174	26.0 @ 173	
13	26.0 @ 176	26.0 @ 176	26.0 @ 175	26.0 @ 174	26.0 @ 174	
14	25.5 @ 177	25.5 @ 176	25.5 @ 176	25.5 @ 175	25.5 @ 174	

Table 10: No-Sparge Infusion Volume (quarts) @ Temperature (°F), Grist Ratio of 1.2 q/#

Grain (#)	**Grist Temperature (°F)**					
	148	**149**	**150**	**151**	**152**	**153**
8	26.5 @ 176	26.5 @ 176	26.5 @ 175	26.5 @ 175	26.5 @ 175	26.5 @ 174
9	26.0 @ 177	26.0 @ 177	26.0 @ 177	26.0 @ 176	26.0 @ 176	26.0 @ 175
10	25.0 @ 179	25.0 @ 178	25.0 @ 178	25.0 @ 177	25.0 @ 177	25.0 @ 176
11	24.5 @ 180	24.5 @ 180	24.5 @ 179	24.5 @ 178	24.5 @ 178	24.5 @ 177
12	24.0 @ 182	24.0 @ 181	24.0 @ 180	24.0 @ 180	24.0 @ 179	24.0 @ 178
13	23.0 @ 183	23.0 @ 183	23.0 @ 182	23.0 @ 181	23.0 @ 180	23.0 @ 180
14	22.5 @ 185	22.5 @ 184	22.5 @ 183	22.5 @ 182	22.5 @ 182	22.5 @ 181
	154	**155**	**156**	**157**	**158**	
8	26.5 @ 174	26.5 @ 173	26.5 @ 173	26.5 @ 173	26.5 @ 172	
9	26.0 @ 175	26.0 @ 174	26.0 @ 174	26.0 @ 173	26.0 @ 173	
10	25.0 @ 176	25.0 @ 175	25.0 @ 175	25.0 @ 174	25.0 @ 173	
11	24.5 @ 177	24.5 @ 176	24.5 @ 175	24.5 @ 175	24.5 @ 174	
12	24.0 @ 178	24.0 @ 177	24.0 @ 176	24.0 @ 176	24.0 @ 175	
13	23.0 @ 179	23.0 @ 178	23.0 @ 177	23.0 @ 177	23.0 @ 176	
14	22.5 @ 180	22.5 @ 179	22.5 @ 178	22.5 @ 177	22.5 @ 177	

Table 11: No-Sparge Infusion Volume (quarts) @ Temperature (°F), Grist Ratio of 1.5 q/#

Grain (#)	**Grist Temperature (°F)**					
	148	**149**	**150**	**151**	**152**	**153**
8	24.0 @ 179	24.0 @ 179	24.0 @ 178	24.0 @ 177	24.0 @ 177	24.0 @ 176
9	23.0 @ 181	23.0 @ 180	23.0 @ 180	23.0 @ 179	23.0 @ 178	23.0 @ 178
10	22.0 @ 183	22.0 @ 182	22.0 @ 182	22.0 @ 181	22.0 @ 180	22.0 @ 179
11	21.0 @ 185	21.0 @ 185	21.0 @ 184	21.0 @ 183	21.0 @ 182	21.0 @ 181
12	20.0 @ 188	20.0 @ 187	20.0 @ 186	20.0 @ 185	20.0 @ 184	20.0 @ 183
13	19.5 @ 190	19.5 @ 189	19.5 @ 188	19.5 @ 187	19.5 @ 186	19.5 @ 185
14	18.5 @ 193	18.5 @ 192	18.5 @ 191	18.5 @ 189	18.5 @ 188	18.5 @ 187
	154	**155**	**156**	**157**	**158**	
8	24.0 @ 176	24.0 @ 175	24.0 @ 175	24.0 @ 174	24.0 @ 174	
9	23.0 @ 177	23.0 @ 176	23.0 @ 176	23.0 @ 175	23.0 @ 175	
10	22.0 @ 179	22.0 @ 178	22.0 @ 177	22.0 @ 176	22.0 @ 176	

... continued on next page

Table 11: No-Sparge Infusion Volume (quarts) @ Temperature (°F), Grist Ratio of 1.5 q/# (... continued)

Grain (#)	**Grist Temperature (°F)**				
11	21.0 @ 180	21.0 @ 179	21.0 @ 178	21.0 @ 178	21.0 @ 177
12	20.0 @ 182	20.0 @ 181	20.0 @ 180	20.0 @ 179	20.0 @ 178
13	19.5 @ 184	19.5 @ 182	19.5 @ 181	19.5 @ 180	19.5 @ 179
14	18.5 @ 186	18.5 @ 184	18.5 @ 183	18.5 @ 182	18.5 @ 181

Table 12: First Batch-Sparge Infusion Volume (quarts) @ Temperature (°F) (Grist Ratio of 1.0 q/#, 32 quart pre-boil volume)

Grain (#)	**Grist Temperature (°F)**					
	148	**149**	**150**	**151**	**152**	**153**
9	11.5 @ 186	11.5 @ 185	11.5 @ 184	11.5 @ 184	11.5 @ 183	11.5 @ 182
10	11.0 @ 189	11.0 @ 188	11.0 @ 187	11.0 @ 186	11.0 @ 185	11.0 @ 184
11	10.5 @ 192	10.5 @ 191	10.5 @ 190	10.5 @ 189	10.5 @ 188	10.5 @ 186
12	10.0 @ 196	10.0 @ 195	10.0 @ 193	10.0 @ 192	10.0 @ 190	10.0 @ 189
13	10.0 @ 198	10.0 @ 197	10.0 @ 195	10.0 @ 194	10.0 @ 192	10.0 @ 191
14	9.5 @ 202	9.5 @ 201	9.5 @ 199	9.5 @ 197	9.5 @ 196	9.5 @ 194
15	9.0 @ 207	9.0 @ 205	9.0 @ 203	9.0 @ 201	9.0 @ 199	9.0 @ 197
16	9.0 @ 210	8.5 @ 210	8.5 @ 208	8.5 @ 205	8.5 @ 203	8.5 @ 201
17	9.5 @ 210	9.0 @ 210	8.5 @ 210	8.0 @ 210	8.0 @ 208	8.0 @ 205
18	10.0 @ 210	9.5 @ 210	9.0 @ 210	8.5 @ 210	8.0 @ 210	7.5 @ 210
19	10.5 @ 210	10.0 @ 210	9.5 @ 210	9.0 @ 210	8.5 @ 210	8.0 @ 210
20	11.0 @ 210	10.5 @ 210	10.0 @ 210	9.5 @ 210	9.0 @ 210	8.5 @ 210
21	11.5 @ 210	11.0 @ 210	10.5 @ 210	10.0 @ 210	9.5 @ 210	9.0 @ 210
22	12.0 @ 210	11.5 @ 210	11.0 @ 210	10.5 @ 210	10.0 @ 210	9.0 @ 210
23	13.0 @ 210	12.0 @ 210	11.5 @ 210	11.0 @ 210	10.0 @ 210	9.5 @ 210
24	13.5 @ 210	12.5 @ 210	12.0 @ 210	11.5 @ 210	10.5 @ 210	10.0 @ 210
25	14.0 @ 210	13.0 @ 210	12.5 @ 210	12.0 @ 210	11.0 @ 210	10.5 @ 210
	154	**155**	**156**	**157**	**158**	
9	11.5 @ 181	11.5 @ 180	11.5 @ 179	11.5 @ 178	11.5 @ 177	
10	11.0 @ 183	11.0 @ 182	11.0 @ 181	11.0 @ 180	11.0 @ 179	
11	10.5 @ 185	10.5 @ 184	10.5 @ 183	10.5 @ 181	10.5 @ 180	
12	10.0 @ 188	10.0 @ 186	10.0 @ 185	10.0 @ 183	10.0 @ 182	
13	10.0 @ 189	10.0 @ 188	10.0 @ 186	10.0 @ 185	10.0 @ 183	
14	9.5 @ 192	9.5 @ 190	9.5 @ 189	9.5 @ 187	9.5 @ 185	

... continued on next page

Table 12: First Batch-Sparge Infusion Volume (quarts) @ Temperature (°F) (Grist Ratio of 1.0 q/#, 32 quart pre-boil volume) (... continued)

Grain (#)	**Grist Temperature (°F)**				
15	9.0 @ 195	9.0 @ 193	9.0 @ 191	9.0 @ 189	9.0 @ 187
16	8.5 @ 199	8.5 @ 197	8.5 @ 194	8.5 @ 192	8.5 @ 190
17	8.0 @ 203	8.0 @ 200	8.0 @ 198	8.0 @ 195	8.0 @ 193
18	7.5 @ 207	7.5 @ 204	7.5 @ 202	7.5 @ 199	7.5 @ 196
19	7.5 @ 210	7.0 @ 209	7.0 @ 206	7.0 @ 203	7.0 @ 200
20	8.0 @ 210	7.0 @ 210	6.5 @ 210	6.5 @ 208	6.5 @ 204
21	8.0 @ 210	7.5 @ 210	7.0 @ 210	6.5 @ 210	6.0 @ 209
22	8.5 @ 210	8.0 @ 210	7.5 @ 210	6.5 @ 210	6.0 @ 210
23	9.0 @ 210	8.5 @ 210	7.5 @ 210	7.0 @ 210	6.5 @ 210
24	9.5 @ 210	8.5 @ 210	8.0 @ 210	7.5 @ 210	6.5 @ 210
25	9.5 @ 210	9.0 @ 210	8.5 @ 210	7.5 @ 210	7.0 @ 210

Table 13: First Batch-Sparge Infusion Volume (quarts) @ Temperature (°F) (Grist Ratio of 1.2 q/#, 32 quart pre-boil volume)

Grain (#)	**Grist Temperature (°F)**					
	148	**149**	**150**	**151**	**152**	**153**
9	10.0 @ 193	10.0 @ 191	10.0 @ 190	10.0 @ 189	10.0 @ 188	10.0 @ 186
10	9.0 @ 198	9.0 @ 197	9.0 @ 195	9.0 @ 194	9.0 @ 192	9.0 @ 191
11	8.5 @ 203	8.5 @ 202	8.5 @ 200	8.5 @ 198	8.5 @ 196	8.5 @ 195
12	8.0 @ 209	8.0 @ 207	8.0 @ 205	8.0 @ 203	8.0 @ 201	8.0 @ 199
13	8.5 @ 210	8.0 @ 210	7.5 @ 210	7.0 @ 210	7.0 @ 209	7.0 @ 206
14	9.0 @ 210	8.5 @ 210	8.0 @ 210	7.5 @ 210	7.5 @ 210	7.0 @ 210
15	10.0 @ 210	9.5 @ 210	9.0 @ 210	8.5 @ 210	8.0 @ 210	7.5 @ 210
16	10.5 @ 210	10.0 @ 210	9.5 @ 210	9.0 @ 210	8.5 @ 210	8.0 @ 210
17	11.0 @ 210	10.5 @ 210	10.0 @ 210	9.5 @ 210	9.0 @ 210	8.5 @ 210
18	11.5 @ 210	11.0 @ 210	10.5 @ 210	10.0 @ 210	9.5 @ 210	9.0 @ 210
19	12.5 @ 210	12.0 @ 210	11.0 @ 210	10.5 @ 210	10.0 @ 210	9.5 @ 210
20	13.0 @ 210	12.5 @ 210	11.5 @ 210	11.0 @ 210	10.5 @ 210	10.0 @ 210
21	13.5 @ 210	13.0 @ 210	12.5 @ 210	11.5 @ 210	11.0 @ 210	10.5 @ 210
22	14.5 @ 210	13.5 @ 210	13.0 @ 210	12.0 @ 210	11.5 @ 210	10.5 @ 210
23	15.0 @ 210	14.0 @ 210	13.5 @ 210	12.5 @ 210	12.0 @ 210	11.0 @ 210
24	15.5 @ 210	15.0 @ 210	14.0 @ 210	13.5 @ 210	12.5 @ 210	11.5 @ 210
25	16.5 @ 210	15.5 @ 210	14.5 @ 210	14.0 @ 210	13.0 @ 210	12.0 @ 210

... continued on next page

Table 13: First Batch-Sparge Infusion Volume (quarts) @ Temperature (°F) (Grist Ratio of 1.2 q/#, 32 quart pre-boil volume) (... continued)

Grain (#)	Grist Temperature (°F)				
	154	**155**	**156**	**157**	**158**
9	10.0 @ 185	10.0 @ 184	10.0 @ 183	10.0 @ 182	10.0 @ 180
10	9.0 @ 189	9.0 @ 188	9.0 @ 186	9.0 @ 185	9.0 @ 183
11	8.5 @ 193	8.5 @ 191	8.5 @ 189	8.5 @ 187	8.5 @ 186
12	8.0 @ 197	8.0 @ 195	8.0 @ 193	8.0 @ 191	8.0 @ 189
13	7.0 @ 204	7.0 @ 201	7.0 @ 198	7.0 @ 196	7.0 @ 193
14	6.5 @ 209	6.5 @ 206	6.5 @ 203	6.5 @ 200	6.5 @ 197
15	7.0 @ 210	6.5 @ 210	6.0 @ 209	6.0 @ 206	6.0 @ 202
16	7.5 @ 210	7.0 @ 210	6.5 @ 210	5.5 @ 210	5.0 @ 210
17	7.5 @ 210	7.0 @ 210	6.5 @ 210	6.0 @ 210	5.5 @ 210
18	8.0 @ 210	7.5 @ 210	7.0 @ 210	6.5 @ 210	6.0 @ 210
19	8.5 @ 210	8.0 @ 210	7.5 @ 210	7.0 @ 210	6.0 @ 210
20	9.0 @ 210	8.5 @ 210	8.0 @ 210	7.0 @ 210	6.5 @ 210
21	9.5 @ 210	9.0 @ 210	8.0 @ 210	7.5 @ 210	7.0 @ 210
22	10.0 @ 210	9.5 @ 210	8.5 @ 210	8.0 @ 210	7.0 @ 210
23	10.5 @ 210	9.5 @ 210	9.0 @ 210	8.0 @ 210	7.5 @ 210
24	11.0 @ 210	10.0 @ 210	9.5 @ 210	8.5 @ 210	8.0 @ 210
25	11.5 @ 210	10.5 @ 210	10.0 @ 210	9.0 @ 210	8.0 @ 210

Table 14: First Batch-Sparge Infusion Volume (quarts) @ Temperature (°F) (Grist Ratio of 1.5 q/#, 32 quart pre-boil volume)

Grain (#)	Grist Temperature (°F)					
	148	**149**	**150**	**151**	**152**	**153**
9	7.0 @ 210	7.0 @ 209	7.0 @ 207	7.0 @ 204	7.0 @ 202	7.0 @ 200
10	8.0 @ 210	7.5 @ 210	7.0 @ 210	6.5 @ 210	6.5 @ 210	6.0 @ 210
11	8.5 @ 210	8.5 @ 210	8.0 @ 210	7.5 @ 210	7.0 @ 210	6.5 @ 210
12	9.5 @ 210	9.0 @ 210	8.5 @ 210	8.0 @ 210	7.5 @ 210	7.0 @ 210
13	10.5 @ 210	10.0 @ 210	9.5 @ 210	9.0 @ 210	8.5 @ 210	7.5 @ 210
14	11.0 @ 210	10.5 @ 210	10.0 @ 210	9.5 @ 210	9.0 @ 210	8.5 @ 210
15	12.0 @ 210	11.5 @ 210	10.5 @ 210	10.0 @ 210	9.5 @ 210	9.0 @ 210
16	12.5 @ 210	12.0 @ 210	11.5 @ 210	11.0 @ 210	10.0 @ 210	9.5 @ 210
17	13.5 @ 210	13.0 @ 210	12.0 @ 210	11.5 @ 210	11.0 @ 210	10.0 @ 210
18	14.5 @ 210	13.5 @ 210	13.0 @ 210	12.0 @ 210	11.5 @ 210	10.5 @ 210

... continued on next page

Table 14: First Batch-Sparge Infusion Volume (quarts) @ Temperature (°F) (Grist Ratio of 1.5 q/#, 32 quart pre-boil volume) (... continued)

Grain (#)	**Grist Temperature (°F)**					
19	15.0 @ 210	14.5 @ 210	13.5 @ 210	13.0 @ 210	12.0 @ 210	11.5 @ 210
20	16.0 @ 210	15.0 @ 210	14.5 @ 210	13.5 @ 210	12.5 @ 210	12.0 @ 210
21	16.5 @ 210	16.0 @ 210	15.0 @ 210	14.0 @ 210	13.5 @ 210	12.5 @ 210
22	17.5 @ 210	16.5 @ 210	15.5 @ 210	15.0 @ 210	14.0 @ 210	13.0 @ 210
23	18.5 @ 210	17.5 @ 210	16.5 @ 210	15.5 @ 210	14.5 @ 210	13.5 @ 210
24	19.0 @ 210	18.0 @ 210	17.0 @ 210	16.0 @ 210	15.0 @ 210	14.5 @ 210
25	20.0 @ 210	19.0 @ 210	18.0 @ 210	17.0 @ 210	16.0 @ 210	15.0 @ 210
	154	**155**	**156**	**157**	**158**	
9	7.0 @ 198	7.0 @ 196	7.0 @ 194	7.0 @ 192	7.0 @ 189	
10	6.0 @ 207	6.0 @ 204	6.0 @ 201	6.0 @ 199	6.0 @ 196	
11	6.0 @ 210	5.5 @ 210	5.0 @ 210	5.0 @ 208	5.0 @ 205	
12	6.5 @ 210	6.0 @ 210	5.5 @ 210	5.0 @ 210	5.0 @ 210	
13	7.0 @ 210	6.5 @ 210	6.0 @ 210	5.5 @ 210	5.0 @ 210	
14	8.0 @ 210	7.0 @ 210	6.5 @ 210	6.0 @ 210	5.5 @ 210	
15	8.5 @ 210	7.5 @ 210	7.0 @ 210	6.5 @ 210	6.0 @ 210	
16	9.0 @ 210	8.5 @ 210	7.5 @ 210	7.0 @ 210	6.5 @ 210	
17	9.5 @ 210	9.0 @ 210	8.0 @ 210	7.5 @ 210	6.5 @ 210	
18	10.0 @ 210	9.5 @ 210	8.5 @ 210	8.0 @ 210	7.0 @ 210	
19	10.5 @ 210	10.0 @ 210	9.0 @ 210	8.5 @ 210	7.5 @ 210	
20	11.0 @ 210	10.5 @ 210	9.5 @ 210	8.5 @ 210	8.0 @ 210	
21	11.5 @ 210	11.0 @ 210	10.0 @ 210	9.0 @ 210	8.5 @ 210	
22	12.0 @ 210	11.5 @ 210	10.5 @ 210	9.5 @ 210	8.5 @ 210	
23	13.0 @ 210	12.0 @ 210	11.0 @ 210	10.0 @ 210	9.0 @ 210	
24	13.5 @ 210	12.5 @ 210	11.5 @ 210	10.5 @ 210	9.5 @ 210	
25	14.0 @ 210	13.0 @ 210	12.0 @ 210	11.0 @ 210	10.0 @ 210	

Hop Utilization

Equations

Bittering units:

$$\textbf{IBU} = U\left(\frac{\textbf{AA} \times H \times 7490}{V_r}\right)$$

Weight of hops to reach a particular IBU:

$$H = \frac{\textbf{IBU} \times V_r}{7490 \times U \times \textbf{AA}}$$

- **IBU** = International Bittering Units
- U = Utilization (from table below)
- **AA** = Alpha Acid level in hops (for example, 0.11)
- H = Amount of hops added (ounces)
- V_r = Batch size (gallons)

Tables

Table 15: Utilization Table (whole hops, loose)

Time (min)	Boil Gravity 1.030	1.040	1.050	1.060	1.070	1.080	1.090	1.100
3	0.034	0.031	0.029	0.026	0.024	0.022	0.020	0.018
6	0.065	0.059	0.054	0.049	0.045	0.041	0.038	0.035
9	0.092	0.084	0.077	0.070	0.064	0.059	0.054	0.049
12	0.116	0.106	0.097	0.088	0.081	0.074	0.068	0.062
15	0.137	0.125	0.114	0.105	0.096	0.087	0.080	0.073
18	0.156	0.142	0.130	0.119	0.109	0.099	0.091	0.083
21	0.173	0.158	0.144	0.132	0.120	0.110	0.101	0.092
24	0.187	0.171	0.157	0.143	0.131	0.120	0.109	0.100
27	0.201	0.183	0.168	0.153	0.140	0.128	0.117	0.107
30	0.212	0.194	0.177	0.162	0.148	0.135	0.124	0.113
33	0.223	0.203	0.186	0.170	0.155	0.142	0.130	0.119
36	0.232	0.212	0.194	0.177	0.162	0.148	0.135	0.124
39	0.240	0.219	0.200	0.183	0.167	0.153	0.140	0.128
42	0.247	0.226	0.206	0.189	0.172	0.158	0.144	0.132
45	0.253	0.232	0.212	0.194	0.177	0.162	0.148	0.135
48	0.259	0.237	0.216	0.198	0.181	0.165	0.151	0.138
51	0.264	0.241	0.221	0.202	0.184	0.169	0.154	0.141
54	0.269	0.246	0.224	0.205	0.188	0.171	0.157	0.143
57	0.273	0.249	0.228	0.208	0.190	0.174	0.159	0.145
60	0.276	0.252	0.231	0.211	0.193	0.176	0.161	0.147
70	0.285	0.261	0.238	0.218	0.199	0.182	0.166	0.152
80	0.291	0.266	0.243	0.222	0.203	0.186	0.170	0.155
90	0.295	0.270	0.247	0.226	0.206	0.188	0.172	0.157
120	0.301	0.275	0.252	0.230	0.210	0.192	0.176	0.161

Table 16: Utilization Table (whole hops, in mesh bag)

Time (min)	Boil Gravity 1.030	1.040	1.050	1.060	1.070	1.080	1.090	1.100
3	0.031	0.028	0.026	0.023	0.022	0.020	0.018	0.016
6	0.059	0.053	0.049	0.044	0.041	0.037	0.034	0.032
9	0.083	0.076	0.069	0.063	0.058	0.053	0.049	0.044
12	0.104	0.095	0.087	0.079	0.073	0.067	0.061	0.056
15	0.123	0.113	0.103	0.095	0.086	0.078	0.072	0.066
18	0.140	0.128	0.117	0.107	0.098	0.089	0.082	0.075
21	0.156	0.142	0.130	0.119	0.108	0.099	0.091	0.083
24	0.168	0.154	0.141	0.129	0.118	0.108	0.098	0.090
27	0.181	0.165	0.151	0.138	0.126	0.115	0.105	0.096
30	0.191	0.175	0.159	0.146	0.133	0.122	0.112	0.102
33	0.201	0.183	0.167	0.153	0.140	0.128	0.117	0.107
36	0.209	0.191	0.175	0.159	0.146	0.133	0.122	0.112
39	0.216	0.197	0.180	0.165	0.150	0.138	0.126	0.115
42	0.222	0.203	0.185	0.170	0.155	0.142	0.130	0.119
45	0.228	0.209	0.191	0.175	0.159	0.146	0.133	0.122
48	0.233	0.213	0.194	0.178	0.163	0.149	0.136	0.124
51	0.238	0.217	0.199	0.182	0.166	0.152	0.139	0.127
54	0.242	0.221	0.202	0.184	0.169	0.154	0.141	0.129
57	0.246	0.224	0.205	0.187	0.171	0.157	0.143	0.131
60	0.248	0.227	0.208	0.190	0.174	0.158	0.145	0.132
70	0.257	0.235	0.214	0.196	0.179	0.164	0.149	0.137
80	0.262	0.239	0.219	0.200	0.183	0.167	0.153	0.140
90	0.266	0.243	0.222	0.203	0.185	0.169	0.155	0.141
120	0.271	0.248	0.227	0.207	0.189	0.173	0.158	0.145

Table 17: Utilization Table (pelletized hops)

Time (min)	Boil Gravity 1.030	1.040	1.050	1.060	1.070	1.080	1.090	1.100
3	0.037	0.034	0.032	0.029	0.026	0.024	0.022	0.020
6	0.072	0.065	0.059	0.054	0.050	0.045	0.042	0.039
9	0.101	0.092	0.085	0.077	0.070	0.065	0.059	0.054
12	0.128	0.117	0.107	0.097	0.089	0.081	0.075	0.068

... continued on next page

Table 17: Utilization Table (pelletized hops) (... continued)

Time (min)	Boil Gravity 1.030	1.040	1.050	1.060	1.070	1.080	1.090	1.100
15	0.151	0.138	0.125	0.116	0.106	0.096	0.088	0.080
18	0.172	0.156	0.143	0.131	0.120	0.109	0.100	0.091
21	0.190	0.174	0.158	0.145	0.132	0.121	0.111	0.101
24	0.206	0.188	0.173	0.157	0.144	0.132	0.120	0.110
27	0.221	0.201	0.185	0.168	0.154	0.141	0.129	0.118
30	0.233	0.213	0.195	0.178	0.163	0.149	0.136	0.124
33	0.245	0.223	0.205	0.187	0.171	0.156	0.143	0.131
36	0.255	0.233	0.213	0.195	0.178	0.163	0.149	0.136
39	0.264	0.241	0.220	0.201	0.184	0.168	0.154	0.141
42	0.272	0.249	0.227	0.208	0.189	0.174	0.158	0.145
45	0.278	0.255	0.233	0.213	0.195	0.178	0.163	0.149
48	0.285	0.261	0.238	0.218	0.199	0.182	0.166	0.152
51	0.290	0.265	0.243	0.222	0.202	0.186	0.169	0.155
54	0.296	0.271	0.246	0.226	0.207	0.188	0.173	0.157
57	0.300	0.274	0.251	0.229	0.209	0.191	0.175	0.160
60	0.304	0.277	0.254	0.232	0.212	0.194	0.177	0.162
70	0.314	0.287	0.262	0.240	0.219	0.200	0.183	0.167
80	0.320	0.293	0.267	0.244	0.223	0.205	0.187	0.171
90	0.325	0.297	0.272	0.249	0.227	0.207	0.189	0.173
120	0.331	0.303	0.277	0.253	0.231	0.211	0.194	0.177

Boil-off Rate

Equations

Boil-off rate:

$$e = k\pi r^2$$

$$e = 0.007297\pi r^2$$

- e = Boil-off rate, gallons/hour
- k = Boil-off constant, 0.007295
- r = Pot radius, inches

Extraction and Alcohol Level

Equations

Coversion Equations

Gravity to Percent extract:

$$\textbf{°P} = (463 - 205\textbf{G})(\textbf{G} - 1)$$

Percent extract to Gravity:

$$\textbf{G} = 1 + \frac{\textbf{°P}}{259 - 0.879\,\textbf{°P}}$$

Sugar and Alcohol Equations

$$S = \frac{0.0832}{1/\textbf{°P} - 0.00382}$$

$$E = \frac{S \times V_r}{M}$$

$$q = 0.22 + 0.001\textbf{OE}$$

$$\textbf{RE} = \frac{(q \times \textbf{OE}) + \textbf{AE}}{1 + q}$$

$$\textbf{AA} = 100\left(\frac{\textbf{OE} - \textbf{AE}}{\textbf{OE}}\right)$$

$$\textbf{RA} = 100\left(1 - \frac{\textbf{RE}}{\textbf{OE}}\right)$$

$$\%A_w = \frac{\textbf{OE} - \textbf{RE}}{2.07 - 0.0107\textbf{OE}}$$

$$\%A_v = \frac{\%A_w \times \textbf{FG}}{0.794}$$

- **°P** = Percent extract by weight (degrees Plato)
- **G** = Specific gravity at 60°F (for example, 1.064)
- S = Sugar concentration (pounds / gallon)
- M = Amount of grain (pounds)
- V_r = Batch size (gallons)
- E = Extraction efficiency (pounds sugar / pounds grain)
- **SG** = Starting gravity at 60°F
- **FG** = Final gravity at 60°F

- **OE** = Original extract (degrees Plato) = **SG** @ 60°F
- **AE** = Apparent extract (degrees Plato) = **FG** @ 60°F
- q = Simplifying constant
- **RE** = Real extract (degrees Plato)
- **AA** = Apparent attenuation (%)
- **RA** = Real attenuation (%)
- $\%A_w$ = Percent alcohol by weight
- $\%A_v$ = Percent alcohol by volume (typical U. S. measure)

Hydrometer Temperature Correction

Equations

Temperature Correction (valid for $59° \leq T \leq 167°$):

$$\Delta_{\mathrm{G}} = -2.52 - 0.0252T + 0.00112T^2$$

- Δ_{G} = Change in gravity
- T = Sample temperature (°F)

Tables

Table 18: Hydrometer Temperature Correction Table

Temp (°F)	Gravity Correction
60	0.0
65	0.6
70	1.2
75	1.9
80	2.6
85	3.4
90	4.3
95	5.2
100	6.2
105	7.2
110	8.3

... continued on next page

Table 18: Hydrometer Temperature Correction Table (... continued)

Temp (°F)	Gravity Correction
115	9.4
120	10.6
125	11.8
130	13.1
135	14.5
140	15.9
145	17.4
150	18.9
155	20.5
160	22.1
165	23.8

Bottle Priming

Tables

Table 19: Fermentable Sugars Table

Sugar Type	Mass to add 1 volume CO_2 (ounces / gallon)	(grams / gallon)
Corn sugar	0.54	15.4
Honey	0.61	17.4
Dry malt extract	0.94	26.5

Table 20: CO_2 Solubility Table

Temp (°F)	Volumes CO_2
32	1.70
35	1.60
40	1.45
45	1.30
50	1.20
55	1.10

... continued on next page

Table 20: CO_2 Solubility Table (... continued)

Temp (°F)	Volumes CO_2
60	1.00
65	0.92
70	0.85
75	0.78

Table 21: Carbonation Levels by Beer Style

Style	Volumes CO_2
Generic Beer Styles	
British-style ales	1.5—2.0
Porter, stout	1.7—2.3
Belgian ales	1.9—2.4
European lagers	2.2—2.7
American ales & lagers	2.2—2.7
Lambic	2.4—2.8
Fruit lambic	3.0—4.5
German wheat beer	3.3—4.5
Specific Beer Styles	
American Amber Ale	2.2—2.8
American Brown	1.5—2.5
American Lager	2.5—2.7
American Pale Ale	2.2—2.8
American Pilsener	2.6—2.7
American Wheat	2.3—2.6
Bamberg Rauchbier	2.2—2.6
Barley Wine	1.3—2.3
Belgian Dubbel	1.9—2.4
Belgian Fruit Lambic	2.6—4.5
Belgian Lambic	3.0—4.5
Belgian Ale	1.9—2.5
Belgian Tripel	1.9—2.4
Belgian White (Wit)	2.1—2.6
Berliner Weisse	3.5
Bock	2.2—2.7

... continued on next page

Table 21: Carbonation Levels by Beer Style (... continued)

Style	Volumes CO_2
Bohemian Pilsener	2.3—2.5
California Common	2.4—2.8
Cream Ale	2.6—2.7
Doppelbock	2.3—2.6
Dortmunder Export	2.6
Dunkelweizen	3.6—4.5
Dusseldorf Altbier	2.2—3.1
Eisbock	2.4
English Bitter	0.8—1.3
English Brown	1.5—2.3
English Mild	1.3—2.0
English Old/Strong Ale	1.5—2.3
English Pale Ale	1.5—2.3
Flanders Brown	1.9—2.5
Foreign-Style Stout	2.3—2.6
German Pilsener	2.5
Helles Bock	2.2—2.7
Imperial Stout	1.5—2.3
India Pale Ale	1.5—2.3
Irish Dry Stout	1.6—2.0
Kölsch	2.4—2.7
Maibock	2.2—2.7
Merzen/Oktoberfest	2.6—2.7
Munchner Helles	2.3—2.7
Munich Dunkel	2.2—2.7
Oud Bruin	1.9—2.5
Porter	1.7—2.5
Schwarzbier	2.2—2.6
Scottish Ale	0.8—1.3
Strong Scotch Ale	1.5—2.3
Sweet Stout	2.0—2.4
Vienna	2.4—2.6
Weizen/Weissbier	3.6—4.5
Weizenbock	3.7—4.7

Kegging

Equations

Line Resistance

Pressure drop per foot in $\frac{3}{16}$ inch beverage tubing ~ 2 psi

$$v = 2.165 + 0.1482p - 0.02075t - 0.001377pt$$

$$p = \frac{v + 0.02075t - 2.165}{0.1482 - 0.001377t}$$

- v = Volumes of CO_2
- p = Pressure (psi)
- t = Temperature (°F)

Tables

Table 22: Force Carbonation Table

Temp (°F)	Volumes CO_2								
	1.5	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0
40	2	3	5	7	9	11	14	16	18
41	2	3	5	7	10	12	14	16	18
42	2	3	6	8	10	12	14	17	19
43	3	4	6	8	10	13	15	17	19
44	3	4	6	9	11	13	15	18	20
45	3	4	7	9	11	14	16	18	21
46	3	5	7	9	12	14	16	19	21
47	4	5	7	10	12	14	17	19	22
48	4	5	8	10	13	15	17	20	22
49	4	6	8	11	13	16	18	20	23
50	5	6	8	11	14	16	19	21	24
51	5	6	9	11	14	17	19	22	24
52	5	7	9	12	15	17	20	22	25
53	6	7	10	12	15	18	20	23	26
54	6	8	10	13	16	18	21	24	26
55	7	8	11	13	16	19	22	25	27
56	7	8	11	14	17	20	22	25	28
57	7	9	12	15	17	20	23	26	29

... continued on next page

Table 22: Force Carbonation Table (... continued)

Temp (°F)	Volumes CO_2 1.5	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0
58	8	9	12	15	18	21	24	27	30
59	8	10	13	16	19	22	25	28	31
60	9	10	13	16	20	23	26	29	32
61	9	11	14	17	20	23	26	30	33
62	10	11	15	18	21	24	27	31	34
63	10	12	15	19	22	25	28	32	35
64	11	13	16	19	23	26	29	33	36
65	12	13	17	20	24	27	30	34	37
66	12	14	18	21	25	28	31	35	38
67	13	15	18	22	25	29	33	36	40
68	14	16	19	23	27	30	34	37	41
69	14	16	20	24	28	31	35	39	43
70	15	17	21	25	29	33	36	40	44