CEMENTING CALCULATIONS

Cementing calculations are an essential part of the designing stage of a cement job. Here, accepted methods and examples are given for:

- Slurry related calculation, weight, yield, and water requirements.
- Fill-up calculations.
- Balancing a cement plug by the "balanced-plug" method.
- Pressure-related calculations, hydrostatic pressure, frictional Pressure, and Horsepower needs.
- Turbulent flow rate.

Slurry calculations

Used in conjunction with fill-up calculations, the slurry weight, slurry volume, and water requirement calculations determine the proper amount of dry-blended cement and water needed for a particular job.

Calculation aids. The following will help in making calculation.
All additive concentrations except salt are based on the weight of cement. When using blended cement systems, the additives are based on the weight of the mixture of cements. Salt percentages are based on the weight of the water. Additives used in low concentrations (less than S%) do not appreciably affect calculations and can generally be ignored. Among such additives are retarders, metasilicate, Diacel A, salt, dispersant, Diacel LWL, KC1, borax and CaC12.

Additives used in larger concentrations are included in the calculations. Such additives are barite, Diacel D, silica sand, Gilsonite, Thixad, and salt.

Class A, C, and H cement weigh 94 lb/sk (sk= sack) and have an absolute volume of 3.60 gal/sk (absolute volume is the volume occupied only by the solids and does not include air. See Table 1).
Commercial lightweight cement weight 75 lb/sk and have an absolute volume of 3.22 gal/sk. Weight and volume of blended pozzolan or talc cement are calculated from the ratio of each component. For example, 50:50 Pozment Class H consists of 1/2 bulk cu.ft. (37 lb) of Pozment and 1/2 bulk cu. ft. (47 lb) of Class H. Water weighs at 8.33 lb/gal at room temperature. Set up a three-column table once the slurry composition is known. (See example calculations).

Material	Wt, lb	Vol, gal

Place the names of the cement and additives in the "material" column. Unless the weight is known in lb, this amount is determined by multiplying the additive percentage time the weight of the cement. Place the volume of the additives in gal. in the "Volume: column. This volume is found by multiplying the additive's weight by the absolute volume column in Table 1. Add up the weight column (lb). Add up the volume column (gal). Divide the weight by the volume to obtain the slurry weight in lb per gal.

Example calculations

Example 1: Calculations

Example 1: Calculate the weight, and yield and the water needed to mix a slurry consisting of Class H, 35 % sand, and 0.5 % retarder, 46% water.

Solution: Since the retarder appears in low concentration, we can neglect it during the calculations without introducing a serious error. As a basis for our calculation we will use a sack of Class H cement. Thus:

Material	Wt Contribution lb	Wt contribution gal
1 sk Class H	94.0	3.60
35 % sand	32.9	1.50
46 % water	43. 2	5.19
Total	170.1 lb	10.29 gal

Slurry weight = 170.1 lb / 10.29 gal = 16.5 lb/gal
Slurry yield = (10.29 gal/sk of cement) (7.48 gal/cu ft)
= 1.376 cu ft/sk
Mixing water = 5.19 gal/sk of cement

Example 2: Calculate the amount of water needed to mix the following slurry at a weight of 17 lb/gal. Assume that dispersant could be added to adjust slurry viscosity if needed.

Solution: Again we can assume that the amount of dispersant is small and can be neglected for the purpose of the calculations. We will call X the % of water. We will use 1 sk of Class H as the basis for the calculations.

Material	**Wt, lb**	**Vol, gal**
1 sk of Class H	94.0	3. 60
35 % sand	32. 9	1. 50
X% water	(X/100) 94	(X/100) 94 (1/8.33)
Total	126.9 +0.94X	5.1 + 0.1128X

Slurry weight = (126.9 + 0.94X) lb/ (5.1 + 0.1128X) gal
= 17 lb/gal

This algebraic equation can be solved for X. The total weight (lb) must equal 17 times the total volume (gal).

126.9+0.94X=86.7+1.918X
40.2 = 0.978X
X = 41.4%

Slurry yield = 5.1 + 0.1128 (41.1) / 7.48 = 1.302 cu ft/sk.
Mixing water = (41.1/100) (94) (1/8.33) = 4.64 gal/sk.

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Example 3: Calculate the pounds of hematite needed to obtain an 18.5 lb/gal slurry if the basic composition is Class H, 35 % sand, hematite and water.

Solution: Here we have, at least on paper, an infinite number of possible solutions since the amount of hematite will change with concentration of water. If we decide on a concentration of water, we can then calculate the amount of hematite needed. Let's say that we would like to consider 46% water. Call X the lb of hematite per sk of cement. Thus;

Material	Wt, lb	Vol, gal
1 sk of Class H	94.0	3.60
35 % sand	32.9	1.50
40 % water	43 . 2	5.19
Xlb hematite	X	0.0239X
Total	170.1 + X	10.29 + 0.0239 X

Slurry weight = 18.5 lb/gal (170.1 + X) (10.29 + 0.0239 X)
Solving for X we get:

X = 36.3 lb hematite/sk of cement

Slurry yield = (10.29 + 0.0239 X) / 7.48 = 1.492 cu ft/sk)
Mixing water = 5.19 gal/sk.

% Water	P-WAH lb/sk	Slurry yield
40	23.0	1.357
42	27.5	1.402
44	34.0	1.455
46	36. 3	1.492

Well conditions, slurry cost, and actual lab testing of the slurry will determine which one to use for the job.

Example 4: Calculate the weight, yield, and water requirement for a slurry of Class H, 18 % salt, and 46 % water.

Solution: Here we have to remember that the salt is based on the weight of the water. Table 2 will be used to aid in the calculations.

Material	**Wt,lb**	**Vol, gal**
1 sk of Class H	94.0	3.60
46 % water	43. 2	5.19
18 % salt	7. 8	0. 3
Total	145.0	9.11

TABLE II

Percent salt **% Salt by wt of water**	**Absolute vol. (dissolved), gal/lb**
2	0.0371
4	0.0378
6	0.0384
8	0.0390
10	0.0394
12	0.0399
14	0.0403
16	0.0407
18	0:0412
20	0.0416
22	0.0420
24	0. 0424
26	0.0428
28	0.0430
30	0.0433
32	0.0436
34	0.0439
36	0.0441
37.2	0.0442

Slurry density = 145.0 / 9.11 = 15.9 lb/.gal.
Slurry yield = 9.11 / 7.48 = 1.22 cu ft/sk of cement
Mixing water = 5.19 gal. sk of cement.

Example 5: A slurry weighing 15.6 lb/gal is desired. Calculate the percent of water if the slurry must also contain 10 % salt.

Solution: Let's call X the percent of water.

Material	Wt, lb	Vol, gal
1 sk Class H	94.0	3.60
X % water	(X/100) (94)	(X/100) (94) (1/8.33)
10 % salt	(X/ 100) (94) (0.1)	(X/ 100) (94) (0.1) (0. 0394)
Total	94.0 + 1.034 X	3.60 X + 0.117 X

Slurry weight = 15.6 lb/gal = (94.0 + 1.034 X) / (3.60 + 0.117X)

Solving for X we get: X = 47.8%

Slurry yield = 3.60 + (0.117) (47.8)/7.48 = 1.229 cu ft/sk
Mixing water= (47.8/100) (94) (1.833) = 5.39 gal/sk

Fill-up calculations

The fill-up calculation determine how much cement slurry is needed to fill the annulus or open hole to a certain height. From this calculation and the slurry calculations, the correct amount of cement blend and water can be brought to location.
Unless a caliper survey is run to determine accurate hole size, always add an excess cement volume to account for hole enlargement. This excess is usually determined by the field experience.
The general procedure outlined here will help in making fill-up calculations. First, determine hole size and pipe size and weight. Then determine the volume to be filled with cement. From the slurry yield, calculate the number of sacks of blended cement:

sk of cement = (volume required, cu ft) / (yield, cu ft/sk)

The excess (safety) factor is multiplied by the sacks of cement to determine the total number of sacks needed on location.
Calculate the volume of water needed on location to mix cement by:

Volume of water for slurry = (sk of cement) (water requirement)

Finally, calculate the displacement volume.

Example 6: Six hundred ft of 13 3/8 in surface casing (68 lb/ft) is to be cemented in a 16" hole using a 116 pcf slurry and 75 % excess.

Solution: From cementer's handbook, the capacity of the annulus to be cemented 0.4206 cu ft/ft.

Slurry volume required = (600 ft) (0.4206 cu ft/ft) = 252.4 cu ft.
Sacks of cement needed = 252.4 cu ft/1.18 cu ft/sk = 214 sk.
Total number of sacks needed including the excess = (214) (1.75) = 375 sk.
Volume of water needed for the slurry = (375 sk) (5.2 gal/sk) (lbbl/42 gal) = 46.4 bbl.

From the cementer's handbook we can also obtain the capacity of the pipe 0.1497 bbl/ft. Therefore, displacement volume needed is:

(600 ft) (0.1497 bbl/ft) = 90 bbl

Balancing a plug

A cement plug must be balanced to help insure that it will be the proper length and in the proper place. If the plug is not balanced, it may migrate down the hole, become contaminated, or fail. The quantities which must be calculated when designing a cementing plug by the balanced plug method include the length of plug; volumes of spacer needed before and after the cement to balance the plug properly; the height of the plug before the pipe is withdrawn; and the volume of displacement fluid needed to balance plug. These examples illustrate the calculations.

Example 7: A 600-ft plug is to be place at a depth of 8,000 ft. The open hole size is 6 1/2 in. Tubing size is 2 3/8 in OD (4.6 lb/ft). Ten bbl of water is to be pumped ahead of the slurry. Slurry yield is 1.18 cu ft/sk. Calculate the number of sacks needed for the job.

Solution: The following equation calculates the number of sacks. $N=(L)\ (C_h)/Y(1)$

Where:
N = Number of sk of cement
L = Plug length, ft
C_h = Hole capacity, cu ft/ft
Y = Slurry yield, cu ft/sk

The hole capacity (Ch) can be obtained from a cementer's handbook.

Back to Equation 1: N = (600) (0. 2304) / 1.18 = 117. 2 sk

Example 8: If 150 sk are mixed (rather than 117) what would be the length of the plug?

Solution: Equation 1 above can be rearranged to solve for L, the length of the plug:

$$L = (N)\ (Y)/C_h \qquad (2)$$

and

$$L=(150)\ (1.18)/0.2304 = 768ft$$

Example 9: Calculate the volume of water to be pumped behind the slurry to balance the plug.

Solution: The following equation will be used.

$$V_b = (C_p)\ (V_a)/C_a \qquad (3)$$

where:

V_a = Volume of spacer ahead of the slurry, bbl
V_b = Volume of spacer behind the slurry, bbl
C_a=Capacity of the annulus, cu ft/ft
C_p = Capacity of the pipe, cu ft/ft

Capacities may be obtained from a handbook

Ca = 0.1997 cu ft/ft
Cp = 0.02171 cu ft/ft

Finally:

$$V_b = (0.02171)\ (10)/0.1997 = 1.09 \text{ bbl}$$

Example 10: Assume that you want to pump a 2-bbl spacer behind the slurry. What is the volume of spacer needed ahead of the slurry to balance the plug?

Solution: Equation 3 can be solved for Va giving:

$$V_a= (C_a)\ (V_b)/C_p \qquad (4)$$

$$V_a= (0.1997)\ (2) / 0.02171 = 1.85 \text{ bbl}$$

Example 11: What is the length of the plug before the pipe is withdrawn from the slurry if we use 117 sk of cement?

Solution: The following equation will be used:

$$L_W = (N)(Y)/C_a + C_p \qquad (5)$$

Where:

L_W= Length of the plug before pipe is withdrawn. Other quantities remain the same as before.

L_W= (117) (1.18)/(0.1997 + 0.02171)
= 138.08/0.22141 = 623.55 ft

The importance of the length of the plug before the pipe is withdrawn will be apparent in the next example.

Example 12: How much mud is to be pumped behind the spacer to balance the plug? (Assuming 10 bbl of water ahead and 1.09 behind the slurry).

Solution: Use the following equation:

$$V_d = [(L_p - L_w)] - V_b \qquad (6)$$

Where:

V_d=Displacement volume needed to balance plug, bbl
L_p = Total length of the pipe, ft
C_p =Capacity of pipe, bbl/ft
V_b =Volume of spacer behind the slurry, bbl
C_p =0.00387 bbl/ft (obtained from handbook)
V_d =(8,000 - 623.55) (0.00387) - 1.09
V_d =28.55 - 1.09 = 27.5 bbl

Many time, to "pull dry pipe", the operator likes to under displace by 1 bbl. If this is the case, the displacement volume to use would be 26.5 bbl.