Engineering Calculations

Introduction

Mud engineers must be capable of making various calculations including: capacities and volumes of pits, tanks, pipes and wellbores; circulation times; annular and pipe mud velocities; and a number of other important calculations. Mud engineering also requires the ability to calculate mud formulations and various dilution scenarios through the addition of solid and liquid components to a mud. Understanding and using the material balance concept, volume fractions, specific gravity and bulk density of materials are all part of being a mud engineer.

U.S. Oilfield and Metric Units

The units of measurement used throughout this manual are U.S. oilfield units. However, metric units are used for many drilling operations around the world. In addition to these two standards, many combinations of units and modified units sets are used. Both U.S. and metric units are illustrated in this section.

Density is expressed in various units and dimensions around the world. The main units of density are lb/gal, kg/m^3 and kg/l (equal to Specific Gravity (SG) and g/cm^3).

U.S. Units	
Mass	Pounds (lb)
Length	Feet (ft) and inches (in.)
Volume, capacity and displacement	Barrels (bbl) and gallons (gal)
Density	Pounds/gallon (lb/gal) and pounds/cubic feet (lb/ft^3)
Pressure	Pounds/square inch (lb/in.^{2} or psi)
Concentration	Pound/barrel (lb/bbl)

Metric Units	
Mass	kilograms (kg)
Length	meters (m)
Volume, capacity and displacement	cubic meters (m^3) and liters (l)
Density	grams/cubic centimeter (g/cm^3) and (kg/l) both same as Specific Gravity (SG)
Pressure	kiloPascals (kPa), bar or atmospheres
Concentration	kilogram/cubic meter (kg/m^3)

The metric system is based on multiples of 10 between like measurements. For example, length can be expressed in multiples of a meter.

1,000 meters (10^3)	1 kilometer (km)
100 meters (10^2)	1 hectometer
10 meters (10^1)	1 dekameter
1/10 meter (10^{-1})	1 decimeter (dm)
1/100 meter (10^{-2})	1 centimeter (cm)
1/1,000 meter (10^{-3})	1 millimeter (mm)
1/1,000,000 meter (10^{-6})	1 micrometer or 1 micron (µm)

Prefixes kilo (1,000), centi (1/100), milli (1/1,000) and micro (1/1,000,000) are used most often. For all other measurements such as mass, volume, density, pressure, etc., the same prefix system can be applied.

Multiply This	By	To Obtain
Volume		
barrel (bbl)	5.615	cubic ft (ft^3)
barrel (bbl)	0.159	cubic meter (m^3)
barrel (bbl)	42	gallon, U.S. (gal)
cubic feet (ft^3)	0.0283	cubic meter (m^3)
cubic feet (ft^3)	7.48	gallon, U.S. (gal)
gallon, U.S. (gal)	0.00379	cubic meter (m^3)
gallon, U.S. (gal)	3.785	liter (l)
cubic meter (m^3)	6.289	barrel (bbl)
cubic meter (m^3)	1,000	liter (l)
Mass or Weight		
pound (lb)	453.6	gram (g)
pound (lb)	0.454	kilogram (kg)
kilogram (kg)	2.204	pound (lb)
metric ton (mt)	1,000	kilogram (kg)
Length		
feet (ft)	0.3048	meter (m)
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
meter (m)	3.281	feet (ft)
miles (mi)	1.609	kilometers (km)
Pressure		
lb/in.^{2} (psi)	6.895	kiloPascal (kPa)
lb/in.^{2} (psi)	0.06895	bar (bar)
lb/in.^{2} (psi)	0.0703	kg/cm^2
kiloPascal (kPa)	0.145	lb/in.^{2} (psi)
bar (bar)	100	kiloPascal (kPa)
Concentration		
pound/barrel (lb/bbl)	2.853	kg/m^3
kilogram/cubic meter (kg/m^3)	0.3505	lb/bbl
Density		
pound/gallon (lb/gal)	119.83	kg/m^3 and g/l
kilogram/cubic meter (kg/m^3)	0.008345	lb/gal
pound/gallon (lb/gal)	0.11983	g/cm^3, kg/l or SG
pound/cubic feet (lb/ft^3)	16.02	kg/m^3 and g/l
g/cm^3, kg/l or SG	8.345	lb/gal

Table 1: Unit conversion factors.

For additional units conversion factors, see the pocket “Fluid Technology Reference” or use the extensive units conversion utility in the MUDWARE® computer program.

General Wellbore Calculations

CAPACITY, VOLUME AND DISPLACEMENT

The **capacity** of a mud pit, a wellbore, an annulus, the inside of a pipe or any other "vessel" is the volume that vessel could hold if it were full (i.e., the maximum possible volume). The capacity of oilfield pits and tanks is usually measured in bbl, gal or m^3. Capacity can also be stated in increments of height, such as bbl/ft, bbl/in., gal/ft, gal/in. or m^3/m. (This can only be done for vessels that have a constant cross-sectional area with height.)

For example, a 10.5-in. diameter well that is 3,922-ft deep contains 420 bbl of mud when full. Therefore, its capacity is 420 bbl regardless of whether it is full or not. This could also be stated as a capacity of 0.107 bbl/ft (420 ÷ 3,922).

Likewise, if the capacity of a mud pit that is 80-in. high is 230 bbl, then the vertical capacity could be stated as 2.87 bbl/in. (230 ÷ 80) or 34.5 bbl/ft (2.87 bbl/in. x 12 in./ft). The capacity of 4.0-in. Outside Diameter (OD), 14.0-lb/ft drill pipe is 0.0108 bbl/ft. Therefore, 10,000 ft of this 4-in. pipe would have a capacity of 108 bbl.

Volume refers to how much mud is actually in a mud pit, wellbore or annulus, or that is inside a pipe or any other vessel. If the vertical capacity (bbl/ft or m^3/m) and mud level depth (ft or m) are known, then the mud depth multiplied by the vertical capacity gives the actual volume (bbl or m^3) of mud in the vessel. If the mud pit mentioned above in the capacity example contained 61 in. of mud, then the mud volume is 2.87 bbl/in. x 61 in. or 175 bbl.

Displacement is the volume of mud that is expelled from the well when the drillstring or casing is run into the hole. Likewise, it is the volume of mud required to fill the well when the pipe is pulled from the hole. Displacement normally represents only the volume of the pipe. The mud inside the pipe is a capacity because the pipe fills with mud as pipe goes into the hole or during circulation. For special situations such as when the bit is plugged or when "floating" casing into the well, the capacity must be added to the displacement of the pipe.

For example, 4.0-in. OD, 14.0-lb/ft drill pipe displaces 0.0047 bbl/ft of mud as it goes into the hole. If 1,000 ft of drill pipe are run into the hole, 4.7 bbl of mud should be "displaced" from the hole. Conversely, when pulling out the same size drill pipe, the well should take 4.7 bbl of mud for every 1,000 ft of pipe removed to keep the hole full.

Calculating Pit and Tank Capacity and Volume

Capacity, volume and displacement calculations use simple volumetric relationships for rectangles, cylinders, concentric cylinders and other shapes with the appropriate unit conversion factors.

Tanks on rigs can be a variety of shapes, but most are either rectangular or cylindrical. Three shapes of tanks are covered here:

1. rectangular.
2. cylindrical, horizontal.
3. cylindrical, vertical.

Mud tanks (also called mud pits) are usually rectangular with parallel sides and ends that are perpendicular to the bottom.

RECTANGULAR PITS

For the typical rectangular pit shown in Figure 1, the capacity can be calculated from the height, width and length.

Where:

V_{Pit} = Pit capacity
L = Pit length
W = Pit width
H = Pit height
M = Mud level height

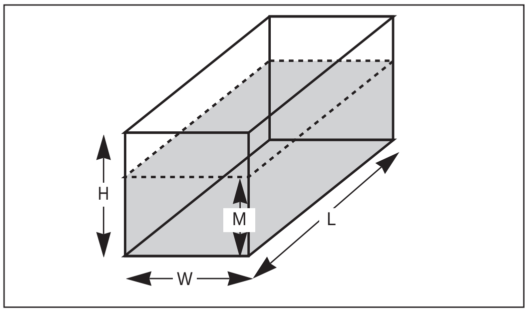


Figure 1: Rectangular mud pit.

The general equation to calculate the capacity of a rectangular vessel is:

Volume = Length x Width x Height

and is valid for both metric and U.S. units.

Therefore, the capacity of a rectangular pit, using feet, is calculated by:

$$V_{Pit}\ (ft^3) = L\ (ft) \times W\ (ft) \times H\ (ft)$$

To convert from ft^3 to U.S. oilfield barrels, divide by 5.61 ft^3/bbl:

$$V_{Pit}\ (bbl) = \frac{L\ (ft) \times W\ (ft) \times H\ (ft)}{5.61\ ft^3/bbl}$$

Expressed in bbl/ft:

$$V_{Pit}\ (bbl/ft) = \frac{L\ (ft) \times W\ (ft)}{5.61\ ft^3/bbl}$$

The actual mud volume (V_{Mud}) in the tank can be calculated using the mud level height M by:

$$V_{Mud}\ (ft^3) = L\ (ft) \times W\ (ft) \times M\ (ft)$$

To convert from ft^3 to U.S. oilfield barrels, divide by 5.61 ft^3/bbl:

$$V_{Mud}\ (bbl) = \frac{L\ (ft) \times W\ (ft) \times M\ (ft)}{5.61\ ft^3/bbl}$$

VERTICAL CYLINDRICAL TANKS

Cylindrical tanks mounted in a vertical position as shown in Figure 2 are used for liquid mud and dry barite storage.

Where:

V_{Cyl} = Capacity cylindrical tank
D = Diameter of cylinder
H = Height of cylinder
M = Material level height
π = 3.1416

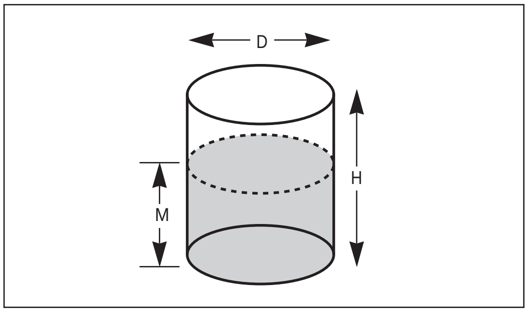


Figure 2: Vertical cylindrical tank.

If the diameter is not known, measure the circumference and divide by 3.1416:

$$D = \frac{\text{tank circumference}}{\pi} = \frac{\text{tank circumference}}{3.1416}$$

The general formula to calculate the capacity for a vertical cylindrical tank is:

$$V_{Cyl} = \frac{\pi D^2 H}{4} = \frac{3.1416\ D^2\ H}{4} = \frac{D^2\ H}{1.273}$$

this is valid for both metric and U.S. units. Therefore, the capacity of a cylindrical pit is calculated by:

$$V_{Cyl}\ (ft^3) = \frac{\pi \text{ x } D^2 (ft) \text{ x } H (ft)}{4} = \frac{3.1416 \text{ x } D^2 (ft) \text{ x } H (ft)}{4} = \frac{D^2 (ft) \text{ x } H (ft)}{1.273}$$

$$V_{Cyl}\ (m^3) = \frac{\pi \text{ x } D^2 (m) \text{ x } H (m)}{4} = \frac{3.1416 \text{ x } D^2 (m) \text{ x } H (m)}{4} = \frac{D^2 (m) \text{ x } H (m)}{1.273}$$

To convert from liquid ft^3 to barrels, divide by 5.61 ft^3/bbl:

$$V_{Cyl}\ (bbl) = \frac{\pi \text{ x } D^2 (ft) \text{ x } H (ft)}{4 \text{ x } 5.61 (ft^3/bbl)} = \frac{D^2 (ft) \text{ x } H (ft)}{7.143}$$

To convert dry ft^3 of a powder to pounds, use bulk density. To obtain the number of 100-lb sacks (sx) of barite, multiply ft^3 by 1.35 (135 lb/ft^3 bulk density):

$$V_{Cyl}\ (100\text{-lb sx}) = \frac{\pi\ D^2 (ft) \text{ x } H (ft) \text{ x } 1.35 (100\text{-lb sx}/ft^3)}{4}$$

$$= 1.06\ (100\text{-lb sx}/ft^3) \text{ x } D^2 (ft) \text{ x } H (ft)$$

The actual mud volume (V_{Mud}) of a vertical cylindrical tank is calculated using the mud/material level height (M) by:

$$V_{Mud}\ (ft^3 \text{ or } m^3) = \frac{\pi \text{ x } D^2\ M}{4} = \frac{D^2\ M}{1.273}$$

HORIZONTAL CYLINDRICAL TANKS

Cylindrical tanks mounted in a horizontal position as shown in Figure 3 are used primarily for storage of diesel fuel, other liquids and barite. The vertical capacity and volume of a horizontal cylindrical tank varies with horizontal cross-section area and is not a linear function of height. Charts and tabular methods are available to calculate the capacity and volume of horizontal cylindrical tanks. These values can also be calculated as follows, resulting in ft^3 if feet are used, m^3 if meters are used, etc.

Where:

V_{Cyl} = Capacity cylindrical tank
D = Diameter of cylinder
L = Length of cylinder
M = Mud or material height
π = 3.1416

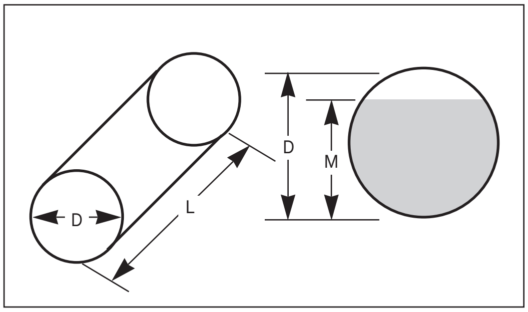


Figure 3: Horizontal cylindrical tank.

$$V_{Cyl} = \frac{L}{2}\left[(2M - D)\sqrt{MD - M^2} + \frac{D^2}{2}\sin^{-1}\left(\frac{2M}{D} - 1\right) + \frac{\pi D^2}{4}\right]$$

[The result from $\sin^{-1}$ must be in radians before being added to the other parts of the equation (2π radians = 360°). To convert from degrees, divide by 57.3 (degree/radian) to obtain radians.]

VOLUME CONVERSIONS

For volume conversions of stored mud additives:

- To convert liquid ft^3 to barrels, divide by 5.61.
- To convert dry ft^3 to pounds, use bulk density as listed on the product bulletin.
- For barite, to obtain the number of 100-lb sacks, multiply ft^3 by 1.35 (135 lb/ft^3 bulk density/100 lb per sack).
- To convert barrels to gallons multiply by 42.

NOTE: Do not confuse the unit "barrel" with "drum." A U.S. drum has a capacity of 55 gal, not 42 gal.

Capacity, Volume and Displacement

WELLBORE VOLUME

While hole volumes are usually calculated with pipe in the hole, occasionally we need to know the capacity of the well without pipe. The vertical capacity of a well interval can be calculated by using the equation for a vertical cylindrical vessel. A wellbore usually consists of several hole intervals, with larger diameters near the surface progressing to smaller sections with increasing depth. To obtain the capacity of the entire wellbore, each interval must be calculated individually, then added together.

NOTE: For "open hole" intervals, the actual hole size may be considerably larger than the bit size due to wellbore enlargement.

The volume of each section can be calculated from the equation for a cylinder:

$$V_{Section} = \frac{\pi D^2 L}{4} = \frac{3.1416 \text{ x } D^2_{Well} \text{ x } L}{4} = \frac{D^2_{Well} \text{ x } L}{1.273}$$

Where:

D_{Well} = Internal Diameter (ID) of the casing, liner or open hole
L = Length of interval

When the hole size or diameter (D_{Well}) is given in inches:

$$V_{Section} \text{ (bbl/ft)} = \frac{D^2_{Well} \text{ (in.)}}{1{,}029}$$

Conversion factor U.S. units:

$$\frac{3.1416}{4} \text{ x } \frac{1 \text{ ft}^2}{144 \text{ in.}^2} \text{ x } \frac{1 \text{ bbl}}{5.61 \text{ ft}^3} = \frac{1}{1{,}029}$$

Many areas use inches for hole and bit diameter, but the metric system for other values. In this case, the volume can be calculated as follows:

$$V_{Section} \text{ (m}^3\text{/m)} = \frac{D^2_{Well} \text{ (in.)}}{1{,}974}$$

Conversion factor metric units (if diameter is in in.):

$$\frac{3.1416}{4} \text{ x } \frac{1 \text{ m}^2}{1{,}550 \text{ in.}^2} = \frac{1}{1{,}974}$$

Conversion factor metric units (if diameter is in mm):

$$V_{Section} \text{ (l/m)} = \frac{3.1416 \text{ x } D^2_{Well}{}^2 \text{ (mm) x } 1{,}000 \text{ (mm/m)}}{4 \text{ x } 1{,}000{,}000 \text{ (mm}^3\text{/l)}}$$

$$= \frac{3.1416 \text{ x } D^2_{Well} \text{ (mm)}}{4{,}000} = \frac{D^2_{Well} \text{ (mm)}}{1{,}273}$$

To convert from liters to cubic meters divide by 1,000.

CAPACITY OF DRILL PIPE OR DRILL COLLARS

The hole volume with the drillstring in the hole is the sum of the volume inside the drillstring (capacity) plus the annular volume between the drillstring and casing or open hole.

The capacity or volume inside a drillstring, expressed in bbl/ft, can be determined from the inside diameter of the pipe in inches.

$$V_{Pipe}\ (\text{bbl/ft}) = \frac{ID^2_{Pipe}\ (\text{in.})}{1{,}029}$$

In metric units:

$$V_{Pipe}\ (\text{l/m}) = \frac{ID^2_{Pipe}\ (\text{in.})}{1.974}$$

or

$$V_{Pipe}\ (\text{l/m}) = \frac{3.1416 \text{ x } ID^2_{Pipe}\ (\text{mm})}{4{,}000} = \frac{ID^2_{Pipe}\ (\text{mm})}{1{,}273}$$

To convert from liters to cubic meters divide by 1,000.

ANNULAR VOLUME

Annular volume or capacity is calculated by subtracting the areas of the two circles that define the annulus.

The annular volume in bbl/ft can be determined from the OD of pipe and ID of casing or open hole in inches.

$$V_{Annulus}\ (\text{bbl/ft}) = \frac{ID^2_{Well}\ (\text{in.}) - OD^2_{Pipe}\ (\text{in.})}{1{,}029}$$

Where:

ID_{Well} = Inside diameter of open hole or casing

OD_{Pipe} = Outside diameter of drill pipe or drill collars

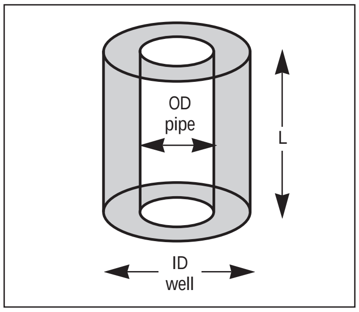


Figure 4: Annular volume.

In metric units:

$$V_{Annulus}\ (\text{l/m}) = \frac{ID^2_{Well}\ (\text{in.}) - OD^2_{Pipe}\ (\text{in.})}{1.974}$$

or

$$V_{Annulus}\ (\text{l/m}) = \frac{ID^2_{Well}\ (\text{mm}) - OD^2_{Pipe}\ (\text{mm})}{1{,}273}$$

To convert from liters to cubic meters divide by 1,000.

The annular volume can also be determined by subtracting the displacement and capacity of a pipe from the capacity of a hole or casing.

$$V_{Annulus} = \text{Capacity}_{Well} - \text{Displacement}_{Drillstring} - \text{Capacity}_{Drillstring}$$

DISPLACEMENT

An estimate of the drillstring displacement ($V_{\text{Pipe Displ.}}$) can be made using the OD and ID of drill pipe and drill collars.

$$V_{\text{Pipe Displ.}}\ (\text{bbl/ft}) = \frac{OD^2_{\text{Pipe}}\ (\text{in.}) - ID^2_{\text{Pipe}}\ (\text{in.})}{1{,}029}$$

Where:

OD_{Pipe} = Outside diameter of drill pipe or drill collars
ID_{Pipe} = Inside diameter of drill pipe or drill collars

In metric units:

$$V_{\text{Pipe Displ.}}\ (\text{l/m}) = \frac{OD^2_{\text{Pipe}}\ (\text{in.}) - ID^2_{\text{Pipe}}\ (\text{in.})}{1.974}$$

or

$$V_{\text{Pipe Displ.}}\ (\text{l/m}) = \frac{OD^2_{\text{Pipe}}\ (\text{mm}) - ID^2_{\text{Pipe}}\ (\text{mm})}{1{,}273}$$

To convert from liters to cubic meters divide by 1,000.

For more exact volumes, the capacity and displacement values from Tables 2, 3, 4a, 4b, 5 and 6 should be used to compensate for the influence of the drill pipe tool joints.

Diameter (in.)	Capacity (bbl/ft)	Capacity (m^3/m)
3½	0.0119	0.0062
3⅞	0.0146	0.0076
4¼	0.0175	0.0092
4½	0.0197	0.0103
4¾	0.0219	0.0114
5¼	0.0268	0.0140
5⅝	0.0307	0.0160
5¾	0.0321	0.0168
5⅞	0.0335	0.0175
6	0.0350	0.0182
6⅛	0.0364	0.0190
6¼	0.0379	0.0198
6½	0.0410	0.0214
6¾	0.0443	0.0231
7⅜	0.0528	0.0276
7⅝	0.0565	0.0295
7⅞	0.0602	0.0314
8⅜	0.0681	0.0355
8½	0.0702	0.0366
8⅝	0.0723	0.0377
8¾	0.0744	0.0388
9½	0.0877	0.0457
9⅝	0.0900	0.0469
9⅞	0.0947	0.0494
10⅝	0.1097	0.0572
11	0.1175	0.0613
12¼	0.1458	0.0760
14¾	0.2113	0.1102
15	0.2186	0.1140
16	0.2487	0.1297
17½	0.2975	0.1552
18	0.3147	0.1642
20	0.3886	0.2027
22	0.4702	0.2452
24	0.5595	0.2919

Table 2: Capacity of open hole.

OD		Weight		ID		Capacity		Displacement	
in.	mm	lb/ft	kg/m	in.	mm	bbl/ft	m³/m	bbl/ft	m³/m
4½	114	13.50	20.12	3.920	100	0.0149	0.0078	0.0047	0.0025
4½	114	15.10	22.50	3.826	97	0.0142	0.0074	0.0055	0.0029
4¾	121	16.00	23.84	4.082	104	0.0162	0.0084	0.0057	0.0030
5	127	15.00	22.35	4.408	112	0.0189	0.0099	0.0054	0.0028
5	127	18.00	26.82	4.276	109	0.0178	0.0093	0.0065	0.0034
5½	140	20.00	29.80	4.778	121	0.0222	0.0116	0.0072	0.0038
5½	140	23.00	34.27	4.670	119	0.0212	0.0111	0.0082	0.0043
5¾	146	22.50	33.53	4.990	127	0.0242	0.0126	0.0079	0.0041
6	152	26.00	38.74	5.140	131	0.0257	0.0134	0.0093	0.0049
6⅝	168	32.00	47.68	5.675	144	0.0313	0.0163	0.0114	0.0059
7	178	26.00	38.74	6.276	159	0.0383	0.0200	0.0093	0.0049
7	178	38.00	56.62	5.920	150	0.0340	0.0177	0.0136	0.0071
7⅝	194	26.40	39.34	6.969	177	0.0472	0.0246	0.0093	0.0049
7⅝	194	33.70	50.21	6.765	172	0.0445	0.0232	0.0120	0.0063
7⅝	194	39.00	58.11	6.625	168	0.0426	0.0222	0.0138	0.0072
8⅝	219	38.00	56.62	7.775	197	0.0587	0.0306	0.0135	0.0070
9⅝	244	40.00	59.60	8.835	224	0.0758	0.0395	0.0142	0.0074
9⅝	244	47.00	70.03	8.681	220	0.0732	0.0382	0.0168	0.0088
9⅝	244	53.50	79.72	8.535	217	0.0708	0.0369	0.0192	0.0100
10¾	273	40.50	60.35	10.050	255	0.0981	0.0512	0.0141	0.0074
10¾	273	45.50	67.80	9.950	253	0.0962	0.0502	0.0161	0.0084
10¾	273	51.00	75.99	9.850	250	0.0942	0.0491	0.0180	0.0094
11¾	298	60.00	89.40	10.772	274	0.1127	0.0588	0.0214	0.0112
13⅜	340	54.50	81.21	12.615	320	0.1546	0.0806	0.0192	0.0100
13⅜	340	68.00	101.32	12.415	315	0.1497	0.0781	0.0241	0.0126
16	406	65.00	96.85	15.250	387	0.2259	0.1178	0.0228	0.0119
16	406	75.00	111.75	15.124	384	0.2222	0.1159	0.0265	0.0138
18⅝	473	87.50	130.38	17.755	451	0.3062	0.1597	0.0307	0.0160
20	508	94.00	140.06	19.124	486	0.3553	0.1853	0.0333	0.0174

Table 3: Casing.

OD		Weight		ID		Capacity		Displacement	
in.	mm	lb/ft	kg/m	in.	mm	bbl/ft	m³/m	bbl/ft	m³/m
2⅜	60	4.85	7.23	1.995	51	0.0039	0.0020	0.0016	0.0008
2⅞	73	6.85	10.21	2.441	62	0.0058	0.0030	0.0022	0.0012
2⅞	73	10.40	15.50	2.150	55	0.0045	0.0023	0.0035	0.0018
3½	89	13.30	19.82	2.764	70	0.0074	0.0039	0.0045	0.0023
3½	89	15.50	23.10	2.602	66	0.0066	0.0034	0.0053	0.0028
4	102	14.00	20.86	3.340	85	0.0108	0.0057	0.0047	0.0025
4½	114	16.60	24.73	3.826	97	0.0142	0.0074	0.0055	0.0029
4½	114	20.00	29.80	3.640	92	0.0129	0.0067	0.0068	0.0035
5	127	19.50	29.06	4.276	109	0.0178	0.0093	0.0065	0.0034
5	127	20.50	30.55	4.214	107	0.0173	0.0090	0.0070	0.0037
5½	140	21.90	32.63	4.778	121	0.0222	0.0116	0.0072	0.0038
5½	140	24.70	36.80	4.670	119	0.0212	0.0111	0.0082	0.0043
5 9/16	141	22.20	33.08	4.859	123	0.0229	0.0120	0.0071	0.0037
5 9/16	141	25.25	37.62	4.733	120	0.0218	0.0114	0.0083	0.0043
6⅝	168	31.90	47.53	5.761	146	0.0322	0.0168	0.0104	0.0054
7⅝	194	29.25	43.58	6.969	177	0.0472	0.0246	0.0093	0.0049

Table 4a: Drill pipe.

OD		ID		Weight		Capacity		Displacement	
in.	mm	in.	mm	lb/ft	kg/m	bbl/ft	m^3/m	bbl/ft	m^3/m
3½	89	2.063	52	25.30	37.70	0.0042	0.0022	0.0092	0.0048
3½	89	2.250	57	23.20	34.57	0.0050	0.0026	0.0084	0.0044
4	102	2.563	65	27.20	40.53	0.0064	0.0033	0.0108	0.0056
4½	114	2.750	70	41.00	61.09	0.0074	0.0039	0.0149	0.0078
5	127	3.000	76	49.30	73.46	0.0088	0.0046	0.0180	0.0094
5½	140	3.375	86	57.00	84.93	0.0112	0.0058	0.0210	0.0110
6⅝	168	4.500	114	70.80	105.49	0.0197	0.0103	0.0260	0.0136

Table 4b: Heavy-weight drill pipe.

OD		ID		Weight		Capacity		Displacement	
in.	mm	in.	mm	lb/ft	kg/m	bbl/ft	m^3/m	bbl/ft	m^3/m
3½	89	1.500	38	26.64	39.69	0.00219	0.0011	0.0097	0.0051
4⅛	105	2.000	51	34.68	51.67	0.00389	0.0020	0.0126	0.0066
4¾	121	2.250	57	46.70	69.58	0.00492	0.0026	0.0170	0.0089
6	152	2.250	57	82.50	122.93	0.00492	0.0026	0.0301	0.0157
6¼	159	2.250	57	90.60	134.99	0.00492	0.0026	0.0330	0.0172
6½	165	2.813	71	91.56	136.42	0.00768	0.0040	0.0334	0.0174
6¾	171	2.250	57	108.00	160.92	0.00492	0.0026	0.0393	0.0205
7¾	197	2.813	71	138.48	206.34	0.00768	0.0040	0.0507	0.0264
8	203	2.813	71	150.48	224.22	0.00768	0.0040	0.0545	0.0284
9½	241	3.000	76	217.02	323.36	0.00874	0.0046	0.0789	0.0412
10	254	3.000	76	242.98	362.04	0.00874	0.0046	0.0884	0.0461
11¼	286	3.000	76	314.20	468.16	0.00874	0.0046	0.1142	0.0596

Table 5: Drill collars.

Size Nominal	Size OD	ID (in.)	Weight (lb/ft)	Capacity (bbl/ft)
1½	1 5/16	1.610	2.75	0.0025
2	2⅜	1.995	4.60	0.0039
2½	2⅞	2.441	6.40	0.0058
3	3½	2.992	10.20	0.0087
3½	4	3.476	11.00	0.0117
4	4½	3.958	12.60	0.0152

Table 6: API tubing (standard).

Calculating Pump Output

Mud pumps circulate mud under pressure during the drilling operation. Mud pumps are piston pumps and are often called “positive displacement” or “reciprocating” pumps. They have either two or three pistons (swabs) that move forward and backward inside cylinders (liners). One complete forward and backward cycle is called one stroke (stk) and is equal to the rotation of the crankshaft, so 1 stk/min = 1 RPM. Two-piston pumps are called duplex pumps and three-piston pumps are triplex pumps. Triplex pumps are more commonly used today.

Mud pump output can be calculated or is listed in tables and has units of bbl/stk or gal/stk. The actual circulation rate, also called pump output, has units of bbl/min or gal/min. The actual circulation rate is determined by multiplying the pump output (bbl/stk) by the pump rate (stk/min) and a volumetric efficiency. This efficiency is often expressed as a percent and can range from 85 to 100%. Modern mud pumps use charging centrifugal pumps to maintain a positive pressure on the mud pump suction to achieve better efficiency. Mud pump table 7a and 7b in this chapter are for 100% efficiency. Note that all equations below that call for pump output have an efficiency factor included in them.

TRIPLEX MUD PUMPS

The pistons on a triplex mud pump work only on the forward stroke and generally have short strokes (in the 6- to 12-in. range) and operate at rates, in the 60- to 120-stk/min range.

The general equation to calculate output of a triplex pump is:

$$V_{\text{Pump Output}} = \frac{3 \text{ x } 3.1416 \text{ x } ID^2_{\text{Liner}} \text{ x } L \text{ x } Eff}{4}$$

Where:

$V_{\text{Pump Output}}$ = Pump output/stroke
ID_{Liner} = ID liner
L = Length of pump stroke
Eff = Pump efficiency (decimal)

If the liner ID and stroke length are in inches, then the pump output for a triplex mud pump in bbl/stk is:

$$V_{\text{Pump Output}} \text{ (bbl/stk)} = \frac{ID^2_{\text{Liner}} \text{ (in.) x } L \text{ (in.) x } Eff \text{ (decimal)}}{4{,}116}$$

In metric units:

$$V_{\text{Pump Output}} \text{ (l/stk)} = \frac{ID^2_{\text{Liner}} \text{ (in.) x } L \text{ (in.) x } Eff \text{ (decimal)}}{25.90}$$

or

$$V_{\text{Pump Output}} \text{ (l/stk)} = \frac{ID^2_{\text{Liner}} \text{ (mm) x } L \text{ (mm) x } Eff \text{ (decimal)}}{424{,}333}$$

Liner ID (in.)	Stroke Length (in.)									
	7	7½	8	8½	9	9½	10	11	12	14
3	0.015	0.016	0.017	0.019	0.020	0.020	0.022	0.024	0.026	—
3¼	0.018	0.019	0.021	0.022	0.023	0.024	0.026	0.028	0.031	—
3½	0.021	0.022	0.024	0.025	0.027	0.028	0.030	0.033	0.036	—
3¾	0.024	0.026	0.027	0.029	0.031	0.032	0.034	0.038	0.041	—
4	0.027	0.029	0.031	0.033	0.035	0.036	0.039	0.043	0.047	—
4¼	0.031	0.033	0.035	0.037	0.039	0.041	0.044	0.048	0.053	—
4½	0.034	0.037	0.039	0.042	0.044	0.045	0.049	0.054	0.059	—
4¾	0.038	0.041	0.044	0.047	0.049	0.051	0.055	0.060	0.066	—
5	0.043	0.045	0.049	0.052	0.055	0.056	0.061	0.067	0.073	0.085
5¼	0.047	0.050	0.054	0.057	0.060	0.062	0.067	0.074	0.080	0.094
5½	0.051	0.055	0.059	0.062	0.066	0.068	0.073	0.081	0.088	0.103
5¾	0.056	0.060	0.064	0.068	0.072	0.074	0.080	0.088	0.096	0.112
6	0.061	0.065	0.070	0.074	0.079	0.081	0.087	0.096	0.105	0.122
6¼	0.066	0.071	0.076	0.081	0.085	0.088	0.095	0.104	0.114	0.133
6½	0.072	0.077	0.082	0.087	0.092	0.095	0.103	0.113	0.123	0.144
6¾	0.077	0.083	0.088	0.094	0.100	0.102	0.111	0.122	0.133	0.155
7	0.083	0.089	0.095	0.101	0.107	0.110	0.119	0.131	0.143	0.167
7½	—	—	—	—	—	—	0.137	0.150	0.164	0.191
8	—	—	—	—	—	—	0.155	0.171	0.187	0.218

Table 7a: Triplex pump output (bbl/stk).

Liner ID (mm)	Stroke Length (mm)									
	177.8	190.5	203.2	215.9	228.6	241.3	254.0	279.4	304.8	355.6
76.2	0.0024	0.0025	0.0027	0.0030	0.0032	0.0032	0.0035	0.0038	0.0041	—
82.6	0.0029	0.0030	0.0033	0.0035	0.0037	0.0038	0.0041	0.0045	0.0049	—
88.9	0.0033	0.0035	0.0038	0.0040	0.0043	0.0045	0.0048	0.0052	0.0057	—
95.3	0.0038	0.0041	0.0043	0.0046	0.0049	0.0051	0.0054	0.0060	0.0065	—
101.6	0.0043	0.0046	0.0049	0.0052	0.0056	0.0057	0.0062	0.0068	0.0075	—
108.0	0.0049	0.0052	0.0056	0.0059	0.0062	0.0065	0.0070	0.0076	0.0084	—
114.3	0.0054	0.0059	0.0062	0.0067	0.0070	0.0072	0.0078	0.0086	0.0094	—
120.7	0.0060	0.0065	0.0070	0.0075	0.0078	0.0081	0.0087	0.0095	0.0105	—
127.0	0.0068	0.0072	0.0078	0.0083	0.0087	0.0089	0.0097	0.0107	0.0116	0.0135
133.4	0.0075	0.0080	0.0086	0.0091	0.0095	0.0099	0.0107	0.0118	0.0127	0.0149
139.7	0.0081	0.0087	0.0094	0.0099	0.0105	0.0108	0.0116	0.0129	0.0140	0.0164
146.1	0.0089	0.0095	0.0102	0.0108	0.0114	0.0118	0.0127	0.0140	0.0153	0.0178
152.4	0.0097	0.0103	0.0111	0.0118	0.0126	0.0129	0.0138	0.0153	0.0167	0.0194
158.8	0.0105	0.0113	0.0121	0.0129	0.0135	0.0140	0.0151	0.0165	0.0181	0.0211
165.1	0.0114	0.0122	0.0130	0.0138	0.0146	0.0151	0.0164	0.0180	0.0196	0.0229
171.5	0.0122	0.0132	0.0140	0.0149	0.0159	0.0162	0.0176	0.0194	0.0211	0.0246
177.8	0.0132	0.0142	0.0151	0.0161	0.0170	0.1100	0.0189	0.0208	0.0227	0.0266
190.5	—	—	—	—	—	—	0.0218	0.0239	0.0261	0.0304
203.2	—	—	—	—	—	—	0.0246	0.0272	0.0297	0.0347

Table 7b: Triplex pump output (m^3/stk).

DUPLEX MUD PUMPS

The pistons on a duplex mud pump work in both directions, so that the rear cylinder has the pump rod moving through its swept volume and occupying some volume. The difference in calculations for a duplex vs. a triplex pump is that the displacement volume of this pump rod must be subtracted from the volume in one of the cylinders, plus the difference in number of pumping cylinders, 4 for a duplex and 3 for a triplex. Duplex pumps generally have longer strokes (in the 10- to 18-in. range) and operate at lower rate, in the 40- to 80-stk/min range.

The general equation to calculate output of a duplex pump is:

$$V_{\text{Pump Output}} = \frac{2\pi}{4} \text{ x } \left[ID^2_{\text{Liner}} \text{ x } L + (ID^2_{\text{Liner}} - OD^2_{\text{Rod}}) \text{ x } L \right] \text{ x Eff}$$

Where:

$V_{\text{Pump Output}}$ = Pump output/stroke
ID_{Liner} = ID liner
OD_{Rod} = OD rod
L = Length of pump stroke
Eff = Pump efficiency (decimal)

Pump output in bbl/stroke for a duplex pump with the liner ID, rod OD and stroke length are in inches.

$$V_{\text{Pump Output}} \text{ (bbl/stk)} = \left[\frac{2 \text{ x } ID^2_{\text{Liner}} \text{ (in.)} - OD^2_{\text{Rod}} \text{ (in.)}}{6{,}174} \right] \text{ x L (in.) x Eff (decimal)}$$

In metric units:

$$V_{\text{Pump Output}} \text{ (l/stk)} = \left[\frac{2 \text{ x } ID^2_{\text{Liner}} \text{ (in.)} - OD^2_{\text{Rod}} \text{ (in.)}}{38.85} \right] \text{ x L (in.) x Eff (decimal)}$$

or

$$V_{\text{Pump Output}} \text{ (l/stk)} = \left[\frac{2 \text{ x } ID^2_{\text{Liner}} \text{ (mm)} - OD^2_{\text{Rod}} \text{ (mm)}}{636{,}500} \right] \text{ x L (mm) x Eff (decimal)}$$

Annular Velocity

Annular Velocity (commonly referred to as AV) is the average rate at which fluid is flowing in an annulus. A minimum annular mud velocity is needed for proper hole cleaning. This minimum annular velocity depends on a number of factors, including rate of penetration, cuttings size, hole angle, mud density and rheology. This is discussed in the chapter on hole cleaning.

The following equation calculates annular velocity based on pump output and the annular volume of the wellbore:

$$\text{AV} = \frac{\text{pump output}}{\text{annular volume}} = \frac{V_{\text{Pump Output}}}{V_{\text{Ann}}}$$

$$\text{AV (ft/min)} = \frac{V_{\text{Pump Output}}\ \text{(bbl/min)}}{V_{\text{Ann}}\ \text{(bbl/ft)}}$$

$$\text{AV (m/min)} = \frac{V_{\text{Pump Output}}\ \text{(l/min)}}{V_{\text{Ann}}\ \text{(l/m)}}$$

Where:

AV = Annular Velocity
$V_{\text{Pump Output}}$ = Pump output
V_{Ann} = Annular volume

When mud pump output is given in bbl/min and the wellbore ID and pipe OD in inches, the annular velocity in ft/min is:

$$\text{AV (ft/min)} = \frac{V_{\text{Pump Output}}\ \text{(bbl/min)} \times 1{,}029}{\text{ID}_{\text{Well}}^2\ \text{(in.)} - \text{OD}_{\text{Pipe}}^2\ \text{(in.)}}$$

or

$$\text{AV (ft/min)} = \frac{V_{\text{Pump Output}}\ \text{(gal/min)} \times 24.5}{\text{ID}_{\text{Well}}^2\ \text{(in.)} - \text{OD}_{\text{Pipe}}^2\ \text{(in.)}}$$

Where:

ID_{Well} = ID open hole or casing (in.)
OD_{Pipe} = OD drill pipe or drill collars (in.)

In metric units:

$$\text{AV (m/min)} = \frac{V_{\text{Pump Output}}\ \text{(l/min)} \times 1.974}{\text{ID}_{\text{Well}}^2\ \text{(in.)} - \text{OD}_{\text{Pipe}}^2\ \text{(in.)}}$$

or

$$\text{AV (m/min)} = \frac{V_{\text{Pump Output}}\ \text{(l/min)} \times 1{,}273}{\text{ID}_{\text{Well}}^2\ \text{(mm)} - \text{OD}_{\text{Pipe}}^2\ \text{(mm)}}$$

Circulation Times

Total circulation time is the time (or number of strokes) required for mud to circulate from the pump suction down the drillstring, out the bit, back up the annulus to the surface, through the pits and arrive at the pump suction once again.

This time is also called "mud cycle time" and is calculated by:

$$\text{Total circulation time (min)} = \frac{V_{\text{System}}}{V_{\text{Pump Output}}}$$

Where:

V_{System} = Total system volume (active) (bbl or m^3)
$V_{\text{Pump Output}}$ = Pump output (bbl/min or m^3/min)

Total circulation (strokes) = Total circulation time (min) x pump rate (stks/min)

Bottoms-up time is the time (or number of strokes) required for mud to circulate from the bit at the bottom of the hole back up the annulus to the surface. The bottoms-up time is calculated by:

$$\text{Bottoms-up time (min)} = \frac{V_{\text{Annulus}}}{V_{\text{Pump Output}}}$$

Where:

V_{Annulus} = Annular volume (bbl or m^3)
$V_{\text{Pump Output}}$ = Pump output (bbl/min or m^3/min)

Bottoms-up (strokes) = Bottoms-up time (min) x pump rate (stk/min)

Hole-cycle time is the time (or number of strokes) required for mud to circulate from the pump suction down the drillstring, out the bit, then back up the annulus to the surface, as calculated by:

$$\text{Hole cycle time (min)} = \frac{V_{\text{Hole}} - V_{\text{DS Displ}}}{V_{\text{Pump Output}}}$$

Where:

V_{Hole} = Total hole volume (bbl or m^3)
$V_{\text{DS Displ}}$ = Displacement of drillstring (bbl or m^3)
$V_{\text{Pump Output}}$ = Pump output (bbl/min or m^3/min)

Hole cycle (strokes) = Hole cycle time (min) x pump rate (stk/min)

NOTE: Strokes times can also be calculated by dividing a given volume by the pump output in bbl/stk or m^3/stk.

Hydrostatic Pressure

Hydrostatic pressure (P_{HYD}) is the pressure exerted by the weight of a liquid on its "container" and is a function of the density of the fluid and the True Vertical Depth (TVD) as shown by the equation below. In a well, this is the pressure exerted on the casing and open hole sections of the wellbore and is the force that controls formation fluids and prevents wellbore collapse.

Hydrostatic pressure = Mud weight x true vertical depth x conversion factor

U.S. Units:

$$P_{HYD} \text{ (lb/in.}^2\text{)} = \text{Mud weight (lb/gal) x TVD (ft) x } 0.052$$

$$\text{Conversion factor } 0.052 = \frac{12 \text{ in./ft}}{231 \text{ in.}^3\text{/gal}}$$

Metric:

$$P_{HYD} \text{ (bar)} = \frac{\text{Mud weight (kg/l) x TVD (m)}}{10.2}$$

Hydrostatic pressure and wellbore hydraulics are discussed in detail in the chapters on Pressure Prediction, Pressure Control, and Shale and Wellbore Stability.

NOTE: Remember that mud density (mud weight) changes with temperature and pressure. This is most pronounced in deep hot wells when using clear brines, oil- or synthetic-base muds.

Example Problems

Problem 1: Typical Calculations with U.S. Units

Given:
Surface casing: 1,850 ft of 13⅜-in. 48 lb/ft
Intermediate: 8,643 ft of 9⅝-in. 32.30 lb/ft
Liner: 8,300 to 14,500 ft of 7-in. 20 lb/ft
Bit diameter: 6⅛-in.
Total Depth (TD): 17,800 ft
Tapered drillstring: 5-in. drill pipe 19.50 lb/ft to 8,000 ft
3½-in., 13.3 lb/ft to 16,800 ft
1,000 ft of 4¾-in. OD x 2¼-in. ID drill collars
Surface system: Three pits: 7-ft high, 6-ft wide, 31-ft long. In two pits there is 64 in. of mud, and in the remaining pit there is 46 in. of mud with drillstring in hole.
Mud weight: 16.3 lb/gal
Mud pumps: Triplex: 6½-in. x 12-in., 50 stk/min, at 95% efficiency

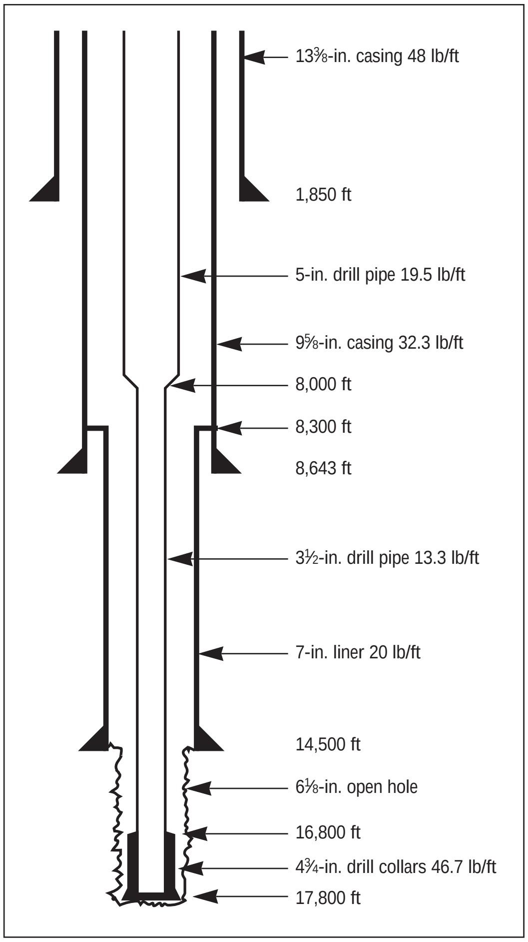


Figure 5: Problem 1 well diagram.

Part I: Determine the total capacity of the surface system in bbl, bbl/ft and bbl/in.

V_{Pit}(ft^3) 1 pit = 6 ft x 31 ft x 7 ft = 1,302 ft^3
V_{Pit}(ft^3) 3 pits = 1,302 x 3 pits = 3,906 ft^3
V_{Pit}(bbl) 3 pits = 3,906 ÷ 5.61 ft^3/bbl = 696.2 bbl
V_{Pit}(bbl/ft) 3 pits = 697.5 ÷ 7 ft = 99.5 bbl/ft
V_{Pit}(bbl/in.) 3 pits = 697.5 ÷ (7 ft x 12 in./ft) = 8.30 bbl/in.

Part II: Determine total mud volume in surface system in bbl.

V_{MUD} (bbl/in.) 1 pit = 8.30 ÷ 3 pits = 2.76 bbl/in.
V_{MUD} (bbl) 3 pits = 2.76 bbl/in. x (64 in. + 64 in. + 46 in.) = 481 bbl

Part III: Determine total hole volume *without* drillstring in the hole.

Calculate mud volume in each hole interval and sum the volumes.

$$V_{Well}\ (9\tfrac{5}{8}\text{-in. casing}) = \frac{9.001^2}{1{,}029} \text{ x } 8{,}300 = 0.0787 \text{ bbl/ft x } 8{,}300 \text{ ft} = 653.5 \text{ bbl}$$

$$V_{Well}\ (7\text{-in. liner}) = \frac{6.456^2}{1{,}029} \text{ x } 6{,}200 = 0.0405 \text{ bbl/ft x } 6{,}200 \text{ ft} = 251.1 \text{ bbl}$$

$$V_{Well}\ (6\tfrac{1}{8}\text{-in. OH}) = \frac{6.125^2}{1{,}029} \text{ x } 3{,}300 = 0.0365 \text{ bbl/ft x } 3{,}300 \text{ ft} = 120.3 \text{ bbl}$$

$$\text{Total } V_{Well} \text{ (w/o DS)} = 653.5 + 251.1 + 120.3 = 1{,}024.9 \text{ bbl}$$

Part IV: Determine total hole volume *with* drill pipe in the hole.

Volume inside drillstring:

$$V_{Pipe}\ (5\text{-in. DP}) = \frac{4.276^2 \text{ bbl/ft}}{1{,}029} \text{ x } 8{,}000 \text{ ft} = 0.0178 \text{ bbl/ft x } 8{,}000 \text{ ft} = 142.2 \text{ bbl}$$

$$V_{Pipe}\ (3\tfrac{1}{2}\text{-in. DP}) = \frac{2.764^2}{1{,}029} \text{ x } 8{,}800 = 0.0074 \text{ bbl/ft x } 8{,}800 \text{ ft} = 65.3 \text{ bbl}$$

$$V_{Pipe}\ (4\tfrac{3}{4}\text{-in. DC}) = \frac{2.25^2}{1{,}029} \text{ x } 1{,}000 = 0.0049 \text{ bbl/ft x } 1{,}000 \text{ ft} = 4.92 \text{ bbl}$$

$$\text{Total } V_P \text{ drillstring} = 142.2 + 65.3 + 4.92 = 212.4 \text{ bbl}$$

Volume in annulus:

$$V_{Ann}\ (\text{Casing} - 5\text{-in. DP}) = \frac{9.001^2 - 5.00^2 \text{ bbl/ft}}{1{,}029} \text{ x } 8{,}000 \text{ ft} = 0.0544 \text{ bbl/ft x } 8{,}000 \text{ ft} = 435.5 \text{ bbl}$$

$$V_{Ann}\ (\text{Casing} - 3\tfrac{1}{2}\text{-in. DP}) = \frac{9.001^2 - 3.5^2}{1{,}029} \text{ x } 300 = 0.0668 \text{ bbl/ft x } 300 \text{ ft} = 20.0 \text{ bbl}$$

$$V_{Ann}\ (\text{Liner} - 3\tfrac{1}{2}\text{-in. DP}) = \frac{6.456^2 - 3.5^2}{1{,}029} \text{ x } 6{,}200 = 0.0286 \text{ bbl/ft x } 6{,}200 \text{ ft} = 177.3 \text{ bbl}$$

$$V_{Ann}\ (\text{OH} - 3\tfrac{1}{2}\text{-in. DP}) = \frac{6.125^2 - 3.5^2}{1{,}029} \text{ x } 2{,}300 = 0.0245 \text{ bbl/ft x } 2{,}300 \text{ ft} = 56.5 \text{ bbl}$$

$$V_{Ann}\ (\text{OH} - 4\tfrac{3}{4}\text{-in. DC}) = \frac{6.125^2 - 4.75^2}{1{,}029} \text{ x } 1{,}000 = 0.0145 \text{ bbl/ft x } 1{,}000 \text{ ft} = 14.6 \text{ bbl}$$

$$\text{Total } V_{Ann} = 435.5 + 20.0 + 177.3 + 56.5 + 14.6 = 703.9 \text{ bbl}$$

$$\text{Total } V_{Well} \text{ (w/pipe)} = 212.4 + 703.9 = 916.3 \text{ bbl}$$

(The total hole volume with pipe in the hole could also be calculated by subtracting the drillstring displacement from the hole capacity calculated in part III.)

Part V: Determine total circulating system volume.

$$\text{Total } V_{System} = 916.4 + 481.0 = 1{,}397.4 \text{ bbl}$$

Part VI: Determine pump output in bbl/min and gal/min; total circulation time (total mud cycle); hole cycle time; and bottoms-up time; in minutes and strokes.

Find pump output from Tables 7a and 7b, 6½ in. x 12 in. = 0.1229 bbl/stk at 100%

PO (bbl/min) = 50 stk/min x 0.1229 bbl/stk x 0.95 = 5.84 bbl/min
PO (gal/min) = 5.84 bbl/min x 42 gal/bbl = 245 gal/min

Total circulation time (min) = 1,397 bbl ÷ 5.84 bbl/min = 239 min
Total circulation (stk) = 239 min x 50 stk/min = 11,950 stk

Hole cycle time (min) = 916.4 bbl ÷ 5.84 bbl/min = 157 min
Hole cycle (stk) = 157 min x 50 = 7,846 stk

Bottoms-up time (min) = 704 ÷ 5.84 = 121 min
Bottoms-up (stk) = 121 min x 50 stk/min = 6,050 stk

Part VII: Determine annular velocity for each annular interval.

AV (OH – 4¾-in. DC) = 5.84 bbl/min ÷ 0.0145 bbl/ft = 402.6 ft/min

AV (OH – 3½-in. DP) = 5.84 bbl/min ÷ 0.0245 bbl/ft = 238.4 ft/min

AV (7-in. liner – 3½-in. DP) = 5.84 bbl/min ÷ 0.0286 bbl/ft = 204.1 ft./min

AV (9⅝-in. casing – 5-in. DP) = 5.84 bbl/min ÷ 0.0544 bbl/ft = 107.4 ft/min

AV (9⅝-in. casing – 3½-in. DP) = 5.84 bbl/min ÷ 0.0668 bbl/ft = 87.4 ft/min

Part VIII: Determine hydrostatic pressure at bottom of hole due to mud density.

P_{HYD} = 17,800 ft x 16.3 lb/gal x 0.052 = 15,087 lb/in.^{2}

PROBLEM 2: TYPICAL CALCULATIONS USING METRIC UNITS

Given:
Surface casing: 1,600 m of 13⅜-in. 48-lb/ft, 323-mm ID
Bit diameter: 250.8 mm (9⅞ in.)
Total depth: 4,200 m
Drillstring: 5-in. 19.50-lb/ft, 127-mm OD, 108.6-mm ID, 200 m of 185-mm OD x 72-mm ID (7¼-in. x 2¾-in.) drill collars
Surface system: 2 pits: 4-m deep, 3-m wide, 10-m long. Both pits have 2.5 m of mud with drillstring in hole.
Mud weight: SG 1.50 or 1,500 kg/m^3
Mud pumps: Triplex: 152.4 mm (6 in.) x 304.8 mm (12 in.), 110 stk/min, at 90% efficiency

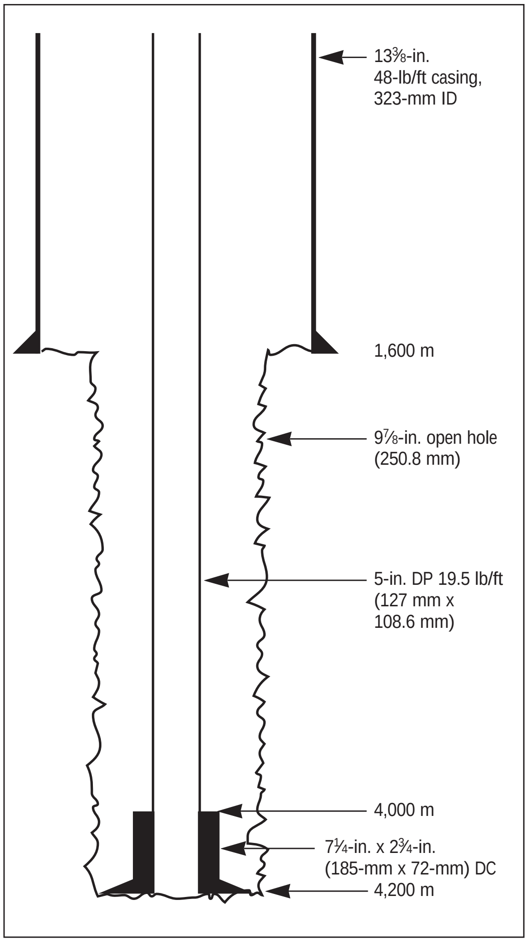


Figure 6: Problem 2 well diagram.

Part I: Determine total capacity of surface system in m^3, m^3/m and m^3/cm.

$$\begin{aligned}
V_{Pit}\ (m^3)\ 1\ pit &= 4\ m \times 3\ m \times 10\ m &&= 120\ m^3\\
V_{Pit}\ (m^3)\ 2\ pits &= 120\ m^3 \times 2 &&= 240\ m^3\\
V_{Pit}\ (m^3/m)\ 2\ pits &= 240\ m^3 \div 4 &&= 60\ m^3/m\\
V_{Pit}\ (m^3/cm)\ 2\ pits &= 60\ m^3/m \div 100\ cm/m &&= 0.60\ m^3/cm
\end{aligned}$$

Part II: Determine total mud volume in surface system in m^3.

$$V_{Mud}\ (m^3)\ 2\ pits = 60\ m^3/m \times 2.5\ m = 150\ m^3$$

Part III: Determine total hole volume without drillstring in the hole.
Calculate mud volume in each hole interval and sum the volumes.

$$V_{Well}\ (m^3) = \frac{ID_{Well}^2\ (mm)}{1,273,000} \times L\ (m)$$

$$V_{Csg}\ (m^3) = \frac{323^2\ mm^2}{1,273,000} \times 1,600\ m = 131.1\ m^3$$

$$V_{OH}\ (m^3) = \frac{250.8^2\ mm^2}{1,273,000} \times 2,600\ m = 128.4\ m^3$$

Total system without drillstring:

$$V_{System} = V_{Csg} + V_{OH} = 131.1\ m^3 + 128.4\ m^3 = 259.5\ m^3$$

Part IV: Determine total hole volume with drillstring in the hole.

Volume inside drillstring:

$$V_{Drillstring}\ (m^3) = \frac{ID_{DS}^2\ (mm)}{1{,}273{,}000}\ \text{x}\ L\ (m)$$

$$V_{DP}\ (m^3) = \frac{108.6^2\ mm^2}{1{,}273{,}000}\ \text{x}\ 4{,}000\ m \qquad = 37.1\ m^3$$

$$V_{DC}\ (m^3) = \frac{72^2\ mm^2}{1{,}273{,}000}\ \text{x}\ 200\ m \qquad = 0.8\ m^3$$

Total volume inside drillstring

$$V_{Drillstring} = V_{DP} + V_{DC} = 37.1\ m^3 + 0.8\ m^3 \qquad = 37.9\ m^3$$

Volume in annulus:

$$V_{Annulus}\ (m^3) = \frac{ID_{Well}^2\ (mm) - OD_{DS}^2\ (mm)}{1{,}273{,}000}\ \text{x}\ L\ (m)$$

$$V_{Ann(Csg\ DP)}(m^3) = \frac{323^2\ mm^2 - 127^2\ mm^2}{1{,}273{,}000}\ \text{x}\ 1{,}600\ m = 0.06927\ \text{x}\ 1{,}600 \quad = 110.8\ m^3$$

$$V_{Ann(OH\ DP)}\ (m^3) = \frac{250.8^2\ mm^2 - 127^2\ mm^2}{1{,}273{,}000}\ \text{x}\ 2{,}400\ m = 0.03673\ \text{x}\ 2{,}400 = 88.2\ m^3$$

$$V_{Ann(OH\ DC)}\ (m^3) = \frac{250.8^2\ mm^2 - 185^2\ mm^2}{1{,}273{,}000}\ \text{x}\ 200\ m = 0.02252\ \text{x}\ 200 \quad = 4.5\ m^3$$

$$V_{Annulus\ Total} = V_{Ann(Csg\ DP)} + V_{Ann\ (OD\ DP)} + V_{Ann\ (OH\ DC)}$$
$$= 110.8\ m^3 + 88.2\ m^3 + 4.5\ m^3 \qquad = 203.5\ m^3$$

$$V_{Well\ w/DS} = V_{Annulus} + V_{DS} = 203.5\ m^3 + 37.9\ m^3 \qquad = 241.4\ m^3$$

Part V: Determine total circulating system volume.

$$V_{Total} = V_{Well/DS} + V_{Surface} = 241.5\ m^3 + 150\ m^3 \qquad = 391.5\ m^3$$

Part VI: Total mud-cycle time and bottoms-up time.

$$V_{Pump\ Output}\ (l/stk) = \frac{ID_{Liner}^2\ (mm)\ \text{x}\ L\ (mm)\ \text{x}\ Eff\ (decimal)}{424{,}333}$$

$$V_{Pump\ Output}\ (l/stk) = \frac{152.4^2 mm^2\ \text{x}\ 304.8\ mm\ \text{x}\ 0.9}{424{,}333} \qquad = 15.01\ l/stk$$

$$V_{Pump\ Output}\ (l/min) = 15.01\ l/stk\ \text{x}\ 110\ stk/min = 1{,}651\ l/min = 1.651\ m^3/min$$

$$\text{Total circulation time (min)} = \frac{391.4\ m^3}{1.651\ m^3/min} \qquad = 237\ min$$

Total circulation (stk) = 237 min x 110 stk/min = 26,070 stk

$$\text{Hole cycle time (min)} = \frac{241.4\ m^3}{1.651\ m^3/min} \qquad = 146\ min$$

Hole cycle (stk) = 146 min x 110 stk/min = 16,060 stk

$$\text{Bottoms-up time (min)} = \frac{203.5\ m^3}{1.651\ m^3/min} \qquad = 123\ min$$

Bottoms-up (stk) = 123 min x 110 stk/min = 13,530 stk

Part VII: Determine annular velocity for each annular interval.

$$AV = \frac{\text{pump output}}{\text{annular volume}} = \frac{V_{\text{Pump Output}}}{V_{\text{ann}}}$$

$$AV_{(\text{OH DC})} = \frac{1.651 \text{ m}^3/\text{min}}{0.02252 \text{ m}^3/\text{m}} = 73 \text{ m/min}$$

$$AV_{(\text{OH DP})} = \frac{1.651 \text{ m}^3/\text{min}}{0.03673 \text{ m}^3/\text{m}} = 45 \text{ m/min}$$

$$AV_{(\text{Casing DP})} = \frac{1.651 \text{ m}^3/\text{min}}{0.06927 \text{ m}^3/\text{m}} = 24 \text{ m/min}$$

Part VIII: Determine hydrostatic pressure at bottom of hole due to mud density.

$$P_{\text{HYD}} = \frac{1.5 \text{ kg/l} \times 4{,}200 \text{ m}}{10.2} = 617.7 \text{ bar}$$

Material Balance

The ability to perform a material balance is essential in drilling fluids engineering. Solids analysis, dilutions, increasing density and blending equations are all based on material balances.

The concept of a material balance is based on the law of conservation of mass that states that mass can be neither created nor destroyed. Simply stated, the sum of the components must equal the sum of the products. This concept is valid for mass and atoms, but it is not always valid for solutions and compounds due to solubilities and chemical reactions. Mathematically, the concept of the material balance is divided into two parts:

I. The total volume equals the sum of the volumes of the individual components.

$$V_{\text{Total}} = V_1 + V_2 + V_3 + V_4 + \ldots$$

II. The total mass equals the sum of the masses of the individual components.

$$V_{\text{Total}}\rho_{\text{Total}} = V_1\,\rho_1 + V_2\,\rho_2 + V_3\,\rho_3 + V_4\,\rho_4 + \ldots$$

Where:
V = Volume
ρ = Density

NOTE: The material balance is valid for both U.S. and metric units as long as the same unit is used for all calculations.

To solve a mass balance, first determine the known and unknown volumes and densities and identify as component or product. Note that the following equations are made in U.S. units, but Table 1 and Table 8 list the conversions for the metric system.

In general, the following steps lead to solving for the unknown:

Step 1. Draw a diagram.
Step 2. Determine components and products, mark volumes, and densities as known or unknown.
Step 3. Develop mass and volume balance.
Step 4. Substitute one unknown into mass balance and solve equation.
Step 5. Determine second unknown and calculate material consumption.

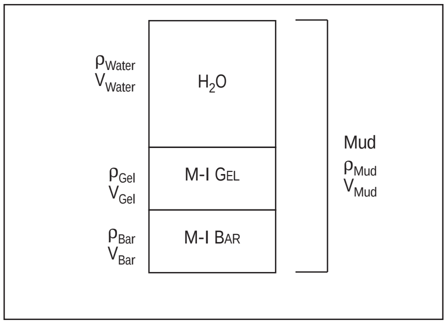


Figure 7a: Example 1 diagram.

EXAMPLE 1: BUILDING WEIGHTED MUD.

Problem: Determine the quantities of materials to build 1,000 bbl (159 m^3) of 16.0 lb/gal (1.92 kg/l) mud with 20 lb/bbl (57 kg/m^3) M-I GEL®, use M-I BAR® as weighting agent.

Step 1. Draw a diagram.
Step 2. Determine densities and volumes with known and unknown.

Components	ρ (lb/gal)	V (bbl)
Water	8.345	?
M-I GEL	21.7	22 (see below)
M-I BAR	35.0	?
Product	—	—
Mud	16.0	1,000

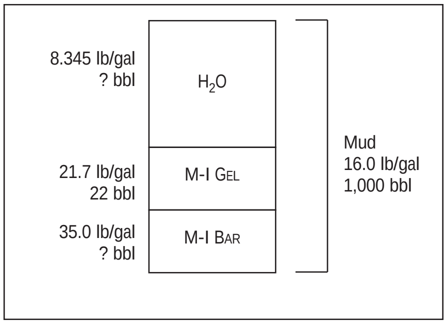


Figure 7b: Example 1: known densities and volumes.

$$V_{Gel} = \frac{20 \text{ lb/bbl x } 1{,}000 \text{ bbl}}{21.7 \text{ lb/gal x } 42 \text{ gal/bbl}} = 22 \text{ bbl}$$

Step 3. Develop mass and volume balance.

$$V_{Mud}\,\rho_{Mud} = V_{Water}\,\rho_{Water} + V_{Gel}\,\rho_{Gel} + V_{Bar}\,\rho_{Bar}$$

$$V_{Mud} = V_{Water} + V_{Gel} + V_{Bar}$$

At this point the mass balance has two unknowns (V_{Bar} and V_{Water}) that can be determined by using both equations. Solve the volume balance for one unknown and then substitute it into the mass balance.

$$1{,}000 \text{ bbl} = V_{Water} + 22 \text{ bbl} + V_{Bar}$$

$$V_{Bar} \text{ (bbl)} = (1{,}000 - 22) - V_{Water} = 978 - V_{Water}$$

Step 4. Substitute one unknown into mass balance and solve equation.

$$V_{Mud}\,\rho_{Mud} = V_{Water}\,\rho_{Water} + V_{Gel}\,\rho_{Gel} + V_{Bar}\,\rho_{Bar}$$

$$1{,}000 \text{ x } 16 = V_{Water} \text{ x } 8.345 + 22 \text{ x } 21.7 + (978 - V_{Water}) \text{ x } 35$$

$$16{,}000 = V_{Water} \text{ x } 8.345 + 477.4 + 34{,}230 - V_{Water} \text{ x } 35$$

$$V_{Water}\,(35 - 8.345) = 477.4 + 34{,}230 - 16{,}000 = 18{,}707.4$$

$$V_{Water} = \frac{18{,}707.4}{26.655} = 702 \text{ bbl}$$

Step 5. Determine second unknown and calculate material consumption.
The volume of barite is derived from the volume balance.

$$V_{Bar} = (978 - V_{Water}) = 978 - 702 \qquad = 276 \text{ bbl}$$

$$lb_{Bar} = 276 \text{ bbl x } (35 \text{ lb/gal x } 42 \text{ gal/bbl}) = 276 \text{ bbl x } 1{,}470 \text{ lb/bbl} = 405{,}720 \text{ lb}$$

$$\text{M-I Bar} = \frac{405{,}720 \text{ lb}}{100 \text{ lb/sx}} \qquad = 4{,}057 \text{ sx}$$

Therefore, to build 1,000 bbl (159 m^3) of 16.0-lb/gal (1.92-kg/l) mud with 20 lb/bbl (57 kg/m^3) M-I Gel, the following amount of material would be required:

Water	701 bbl	111.5 m^3
M-I Gel	200 sx	9,074 kg
M-I Bar	4,057 sx	184.0 mt (1 mt = 1,000 kg)

Use the same equations and substitute the following:

Property	U.S. Unit	Metric	U.S. to Metric Units	Metric to U.S. Units
Density	lb/gal	kg/l	$\text{kg/l} = \frac{\text{lb/gal}}{8.345}$	lb/gal = kg/l x 8.345
Volume	bbl	m^3	$m^3 = \frac{\text{bbl}}{6.29}$	bbl = m^3 x 6.29
Weight	lb	kg	$\text{kg} = \frac{\text{lb}}{2.204}$	lb = kg x 2.204
Weight	lb	tons (mt)	$\text{mt} = \frac{\text{lb}}{2{,}204}$	lb = mt x 2,204
Concentration	lb/bbl	kg/m^3	$\text{kg/m}^3 = \frac{\text{lb/gal}}{2.853}$	lb/gal = kg/m^3 x 2.853
Barite density	35 lb/gal	4.2 kg/l	$\text{kg/l} = \frac{\text{lb/gal}}{8.345}$	lb/gal = kg/l x 8.345
Bentonite density	21.7 lb/gal	2.6 kg/l	$\text{kg/l} = \frac{\text{lb/gal}}{8.345}$	lb/gal = kg/l x 8.345

Table 8: Metric system conversions.

EXAMPLE 2: BUILDING SALTWATER MUD.

Problem: Determine the quantities of material to build 1,000 bbl (159 m^3) of 14.0-lb/gal (1.68-kg/l) mud with 15 lb/bbl (42.8 kg/m^3) M-I Salt Gel® and 150,000 mg/l Cl-, use M-I Bar as weighting agent.

Step 1. Draw a diagram.

Step 2. Determine densities and volumes with known and unknown.

Components	ρ (lb/gal)	V (bbl)
Saltwater	?	?
Salt Gel	21.7	16.5 (see below)
M-I Bar	35.0	?
Product	—	—
Mud	14.0	1,000

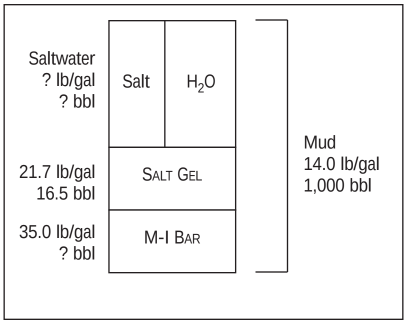


Figure 8: Example 2 diagram.

$$V_{Gel} = \frac{15 \text{ lb/bbl x } 1{,}000 \text{ bbl}}{21.7 \text{ lb/gal x } 42 \text{ gal/bbl}} = 16.5 \text{ bbl}$$

Step 2a. Determine density of saltwater.

To determine the specific gravity of a salt solution, it is normally not valid to use the density of water and sodium chloride and simply solve the mass balance because the volume of salt crystals differs from dissolved salt. Use the following equation to determine the specific gravity of a sodium chloride solution.

$$\rho_{\text{NaCl Solution}} = 1 + 1.166 \text{ x } 10^{-6} \text{ x } (\text{mg/l Cl}^-) - 8.375 \text{ x } 10^{-13} \text{ x } (\text{mg/l Cl}^-)^2 + 1.338 \text{ x } 10^{-18} \text{ x } (\text{mg/l Cl}^-)^3$$

$$\rho(\text{kg/l})_{\text{NaCl Solution}} = 1 + 1.166 \text{ x } 10^{-6} \text{ x } (150{,}000) - 8.375 \text{ x } 10^{-13} \text{ x } (150{,}000)^2 + 1.338 \text{ x } 10^{-18} \text{ x } (150{,}000)^3$$

$$= 1 + 0.1749 - 0.01884 + 0.004516 = 1.1605 \text{ kg/l}$$

$$\rho_{\text{NaCl Solution}} (\text{lb/gal}) = 1.1605 \text{ x } 8.345 = 9.69 \text{ lb/gal}$$

Step 3. Develop mass and volume balance.

$$V_{\text{Mud}}\,\rho_{\text{Mud}} = V_{\text{Saltwater}}\,\rho_{\text{Saltwater}} + V_{\text{Gel}}\,\rho_{\text{Gel}} + V_{\text{Bar}}\,\rho_{\text{Bar}}$$

$$V_{\text{Mud}} = V_{\text{Saltwater}} + V_{\text{Gel}} + V_{\text{Bar}}$$

At this point the mass balance has two unknowns (V_{Bar} and V_{Water}) that can be determined by using both equations. Solve the volume balance for one unknown and then substitute it into the mass balance.

$$1{,}000 \text{ bbl} = V_{\text{Saltwater}} + 16.5 \text{ bbl} + V_{\text{Bar}}$$

$$V_{\text{Bar}} = 1{,}000 \text{ bbl} - 16.5 \text{ bbl} - V_{\text{Saltwater}} = 983.5 \text{ bbl} - V_{\text{Saltwater}}$$

Step 4. Substitute one unknown into mass balance and solve equation.

$$V_{\text{Mud}}\,\rho_{\text{Mud}} = V_{\text{Saltwater}}\,\rho_{\text{Saltwater}} + V_{\text{Gel}}\,\rho_{\text{Gel}} + V_{\text{Bar}}\,\rho_{\text{Bar}}$$

$$1{,}000 \text{ x } 14.0 = V_{\text{Saltwater}} \text{ x } 9.69 + 16.5 \text{ x } 21.7 + 983.5 - V_{\text{Saltwater}} \text{ x } 35$$

$$14{,}000 = V_{\text{Saltwater}} \text{ x } 9.67 + 358.1 + 34{,}422.5 - V_{\text{Saltwater}} \text{ x } 35$$

$$V_{\text{Saltwater}} (35 - 9.69) = 358.1 + 34{,}422.5 - 14{,}000 = 20{,}780.6$$

$$V_{\text{Saltwater}} = \frac{20{,}780.6}{25.31} = 821 \text{ bbl}$$

Step 5. Determine second unknown and calculate material consumption. The volume of barite is derived from the volume balance.

$$V_{\text{Bar}} = V_{\text{Mud}} - V_{\text{Gel}} - V_{\text{Saltwater}} = 1{,}000 - 16.5 - 821 = 162.5 \text{ bbl}$$

$$\text{lb}_{\text{Bar}} = 162.5 \text{ bbl x } (35 \text{ lb/gal x } 42 \text{ gal/bbl}) = 162.5 \text{ bbl x } 1{,}470 \text{ lb/bbl} = 238{,}875 \text{ lb}$$

$$\text{M-I B{\scriptsize AR}} = \frac{238{,}875 \text{ lb}}{100 \text{ lb/sx}} = 2{,}389 \text{ sx}$$

The volume of freshwater that is needed to achieve a saltwater density is determined by using brine tables.

0.913 bbl freshwater x 821 bbl = 749.6 bbl freshwater
86.4 lb/bbl salt x 821 bbl = 70,934 lb = 709 sx

Therefore, to build 1,000 bbl (159 m^3) of 14.0 lb/gal (1.68 kg/l) with 15 lb/bbl (42.8 kg/m^3) SALT GEL and 150,000 mg/l salt, the following amount of material would be required:

Freshwater	750 bbl	119.2 m^3
NaCl	709 sx	32.2 mt
SALT GEL	150 sx	6.8 mt
M-I BAR	2,389 sx	108.4 mt (1 mt = 1,000 kg)

Metric system: Use the same equations and substitute by using conversion factors (see Example 1).

EXAMPLE 3: BLENDING MUD.

Problem: How much of each mud must be blended together to obtain 1,000 bbl ($159\ m^3$) of 14.0-lb/gal (1.68-kg/l) mud?

Available volumes: 1,200 bbl of 11.2-lb/gal mud (mud 1).
1,200 bbl of 15.4-lb/gal mud (mud 2).

Step 1. Draw a diagram.

Step 2. Determine components and products with known and unknowns.

Components	ρ (lb/gal)	V (bbl)
Mud_1	11.2	?
Mud_2	15.4	?
Product	—	—
Blended mud	14.0	1,000

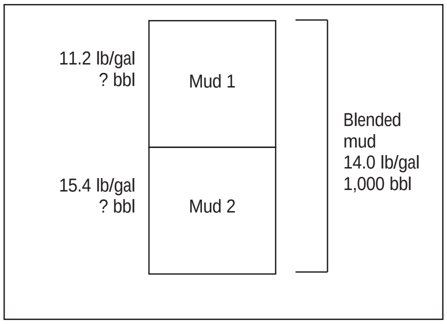


Figure 9: Example 3 blending diagram.

Step 3. Develop mass and volume balance.

$$V_{Final}\,\rho_{Final} = V_{Mud1}\,\rho_{Mud1} + V_{Mud2}\,\rho_{Mud2}$$

$$V_{Final} = V_{Mud1} + V_{Mud2}$$

The mass balance again has two unknowns at this point (V_{Mud1} and V_{Mud2}). Solve the volume balance for one unknown and then substitute it into the mass balance.

$$1{,}000\text{ bbl} = V_{Mud1} + V_{Mud2}$$

$$V_{Mud2} = 1{,}000\text{ bbl} - V_{Mud1}$$

Step 4. Substitute one unknown into mass balance and solve equation.

$$V_{Final}\,\rho_{Final} = V_{Mud1}\,\rho_{Mud1} + V_{Mud2}\,\rho_{Mud2}$$

$$1{,}000 \text{ x } 14 = V_{Mud1} \text{ x } 11.2 + (1{,}000 - V_{Mud1}) \text{ x } 15.4$$

$$14{,}000 = (V_{Mud1} \text{ x } 11.2) + 15{,}400 - (V_{Mud1} \text{ x } 15.4)$$

$$V_{Mud1}\,(15.4 - 11.2) = 15{,}400\text{ bbl} - 14{,}000\text{ bbl} = 1{,}400$$

$$V_{Mud1} = \frac{1{,}400}{(15.4 - 11.2)} = 333.3\text{ bbl}$$

Step 5. Determine second unknown and calculate material consumption.

$$V_{Mud2} = 1{,}000\text{ bbl} - V_{Mud1}$$

$$V_{Mud2} = 1{,}000 - 333.3 = 666.7\text{ bbl}$$

Therefore, to build 1,000 bbl ($159\ m^3$) of 14.0-lb/gal (1.68-kg/l) mud, the following volumes of available muds need to be blended:

333.3 bbl of 11.2-lb/gal mud	$53\ m^3$ of 1.34-kg/l mud
666.7 bbl of 15.4-lb/gal mud	$106\ m^3$ of 1.85-kg/l mud

Metric system: Use the same equations and substitute by using conversion factors (see Example 1).

EXAMPLE 4: INCREASING MUD WEIGHT.

Problem: How much M-I BAR is needed to increase the mud weight of 1,000 bbl (159 m^3) of 14.0-lb/gal (1.68-kg/l) mud to 16.0-lb/gal (1.92-kg/l), and what will the new system volume be?

Increasing the mud weight is very similar to blending muds. Instead of blending muds, it can be treated as blending mud and barite or other weighting material together.

Step 1. Draw a diagram.

Step 2. Determine densities and volumes with known and unknown.

Components	ρ (lb/gal)	V (bbl)
Initial mud	14.0	1,000
M-I BAR	35.0	?
Product	—	—
Mud_{Final}	16.0	?

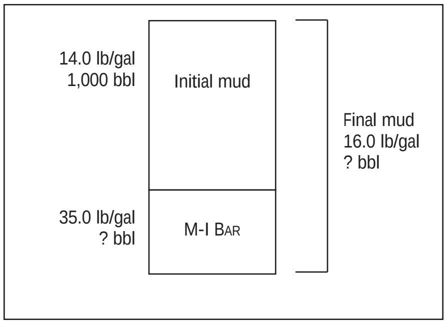


Figure 10: Example 4 diagram.

Step 3. Develop mass and volume balance.

$$V_{Final}\,\rho_{Final} = V_{initial}\,\rho_{initial} + V_{Bar}\,\rho_{Bar}$$

$$V_{Final} = V_{initial} + V_{Bar}$$

The mass balance has two unknowns at this point (V_{Bar} and V_{Final}). Solve the volume balance for one unknown and then substitute this unknown into the mass balance.

$$V_{Final} = V_{initial} + V_{Bar}$$

$$V_{Final} = 1{,}000 \text{ bbl} + V_{Bar}$$

Step 4. Substitute one unknown into mass balance and solve equation.

$$V_{Final}\,\rho_{Final} = V_{initial}\,\rho_{initial} + V_{Bar}\,\rho_{Bar}$$

$$(1{,}000 + V_{Bar}) \text{ x } 16 = 1{,}000 \text{ x } 14 + V_{Bar} \text{ x } 35$$

$$(1{,}000 \text{ x } (16 - 14) = V_{Bar} \text{ x } (35 - 16)$$

$$V_{Bar} = \frac{1{,}000\ (16 - 14)}{(35 - 16)} = \frac{2{,}000}{19} = 105.3 \text{ bbl}$$

$$\text{M-I BAR} = \frac{105.3 \text{ bbl x } 1{,}470 \text{ lb/bbl}}{100 \text{ lb/sx}} = 1{,}548 \text{ sx}$$

Step 5. Determine second unknown and calculate material consumption.

$$V_{Final} = V_{initial} + V_{Bar}$$

$$V_{Final} = 1{,}000 \text{ bbl} + 105.3 \text{ bbl} = 1{,}105.3 \text{ bbl}$$

Therefore, to weight up 1,000 bbl (159 m^3) of 14.0 lb/gal (1.68 kg/l) to 16.0 lb/gal (1.92 kg/l), the following material is required:

1,548 sx of M-I BAR or 70.2 mt (1 mt = 1,000 kg)

The final volume is 1,105.3 bbl (175.7 m^3).

This specific material balance can now be generalized to a weight-up formula for any volume or density.

Weight-up formula (barite) in U.S. units:

$$\text{Barite (lb/bbl)} = 1{,}470\ \frac{(MW_2 - MW_1)}{(35\ \text{lb/gal} - MW_2)}$$

Using lb/gal for density.

Weight-up formula (barite) in metric units:

$$\text{Barite (kg/m}^3\text{)} = 4{,}200\ \frac{(\rho_{desired} - \rho_{initial})}{(4.2\ \text{kg/l} - \rho_{desired})}$$

Using kg/l for density.

EXAMPLE 5: DILUTION/DECREASE OF MUD WEIGHT.

Dilution or decrease of mud weight again can be seen as blending mud, with the water or base oil being treated as mud. The only difference in blending mud is that the final volume is unknown.

Problem: Decrease the weight of 1,000 bbl (159 m^3) of 16.0-lb/gal (1.92-kg/l) mud to 12.0-lb/gal (1.44-kg/l) while allowing the final volume to increase.

Step 1. Draw a diagram.

Step 2. Determine components and products with known and unknowns.

Components	ρ (lb/gal)	V (bbl)
Initial mud	16.0	1,000
Water	8.345	?
Product	—	—
Mud_{Final}	12.0	?

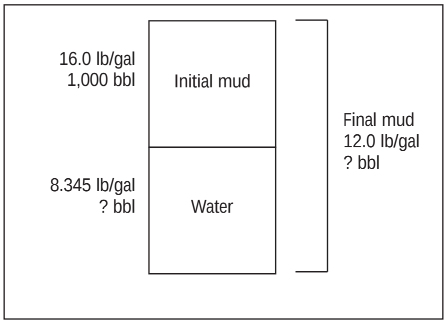


Figure 11: Example 5 diagram.

Step 3. Develop mass and volume balance.

$$V_{Final}\,\rho_{Final} = V_{Mud}\,\rho_{Mud} + V_{Water}\,\rho_{Water}$$

$$V_{Final} = V_{Mud} + V_{Water}$$

At this point the mass balance has two unknowns (V_{Final} and V_{Water}) that can be determined by using both equations. Solve the volume balance for one unknown and then substitute it into the mass balance.

$$V_{Final} = 1{,}000\ \text{bbl} + V_{Water}$$

Step 4. Substitute one unknown into mass balance and solve equation.

$$(1{,}000 + V_{Water}) \times 12.0 = 1{,}000 \times 16.0 + V_{Water} \times 8.345$$

$$12{,}000 + V_{Water} \times 12.0 = 16{,}000 + V_{Water} \times 8.345$$

$$3.655 \times V_{Water} = 4{,}000$$

$$V_{Water} = \frac{4{,}000}{3.655} = 1{,}094\ \text{bbl}$$

Step 5. Determine second unknown.

$$V_{Final} = 1{,}000 + 1{,}094 = 2{,}094\ \text{bbl}$$

Therefore, to decrease the mud weight of 1,000 bbl (159 m^3) of 16.0-lb/gal (1.92-kg/l) mud to 12.0-lb/gal (1.44-kg/l), 1,094 bbl (173.9 m^3) of freshwater are needed.

NOTE: If such a large volume for dilution is required, take into consideration that mixing 1,000 bbl of fresh mud might be easier and more economical than diluting the old mud.

Metric system: Use the same equations and substitute by using conversion factors (see Example 1).

EXAMPLE 6: DECREASE SOLIDS CONTENT.

If the solids-control equipment on the rig is not sufficient to maintain a desired solids content, it is often required to reduce the solids percentage by dilution.

Problem: Decrease the solids content of 1,000 bbl (159 m^3) of mud from 8 to 6% and maintain the mud weight of 12.0 lb/gal (1.44 kg/l).

To solve this problem, the mass balance equation is used with the solids content instead of densities.

Step 1. Draw a diagram.
Step 2. Determine components and products with known and unknowns.

Components	Drill solids (%)	V (bbl)
Initial mud	8	1,000
Water	0	?
Product	—	—
Mud_{Final}	6	?

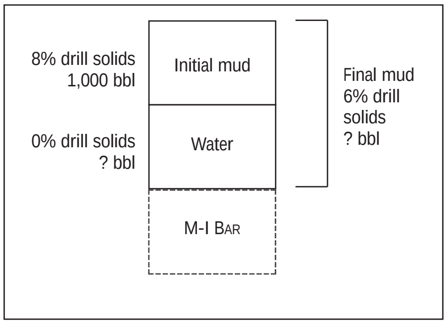


Figure 12: Example 6 diagram.

Step 3. Develop mass and volume balance.

$$V_{Final}DS_{Final} = V_{initial}DS_{initial} + V_{Water}DS_{Water}$$

$$V_{Final} = V_{initial} + V_{Water}$$

The mass balance has two unknowns at this point (V_{Final} and V_{Water}). Solve the volume balance for one unknown and then substitute it into the mass balance.

$$V_{Final} = V_{initial} + V_{Water}$$

$$V_{Final} = 1{,}000 \text{ bbl} + V_{Water}$$

Step 4. Substitute one unknown into mass balance and solve equation.

$$V_{Final}DS_{Final} = V_{initial}DS_{initial} + V_{Water}DS_{Water}$$

$$(1{,}000 \text{ bbl} + V_{Water}) \text{ x } 6\% = 1{,}000 \text{ bbl x } 8\% + V_{Water} \text{ x } 0\%$$

$$6{,}000 + V_{Water} \text{ x } 6 = 8{,}000$$

$$V_{Water} = (8{,}000 - 6{,}000) \div 6 \qquad = 333.3$$

Step 5. Determine second unknown and calculate weight-up.

$$V_{Final} = V_{initial} + V_{Water}$$

$$V_{Final} = 1{,}000 + 333.3 \qquad = 1{,}333.3 \text{ bbl}$$

To maintain the mud weight of 12.0 lb/gal, the 333.3 bbl of water need to be weighted up from 8.345 to 12.0 lb/gal. Use the weight-up formula.

$$\text{Barite (lb/bbl)} = 1{,}470 \frac{(\rho_{desired} - \rho_{initial})}{(35.0 \text{ lb/gal} - \rho_{desired})} = 1{,}470 \frac{(12.0 - 8.345)}{(35 \text{ lb/gal} - 12.0)} = 233.6 \text{ lb/bbl}$$

$$233.6 \text{ lb/bbl x } 333.3 \text{ bbl} = 77{,}859 \text{ lb} \div 100 \text{ lb/sx} \qquad = 779 \text{ sx}$$

Therefore, to decrease the solids content of 1,000 bbl (159 m^3) 12.0-lb/gal (1.44-kg/l) mud from 8 to 6% while maintaining the mud weight, the following amounts are needed:

333.3 (52.9 m^3) bbl of freshwater
779 sx (35.3 mt) of M-I BAR

Solids Analysis

The final use of material balance to be discussed is determining solids analysis. Two cases are discussed, an unweighted freshwater system without oil and a weighted system containing salt and oil.

An unweighted system is discussed first. The only components of this system are Low-Gravity Solids (LGS) and water. For calculation purposes, all low-gravity solids have a density of 21.7 lb/gal (SG 2.6) unless otherwise specified. The product in both cases is the drilling fluid. The diagram for this example is a two-component diagram.

UNWEIGHTED MUD

The material balance and volume equation are as follows:

$$V_{Mud}\rho_{Mud} = V_{Water}\rho_{Water} + V_{LGS}\rho_{LGS}$$

$$V_{Mud} = V_{Water} + V_{LGS}$$

Where:

V_{Mud} = Volume of mud
V_{Water} = Volume of water
V_{LGS} = Volume of Low-Gravity Solids
ρ_{Mud} = Density of mud or mud weight
ρ_{Water} = Density of water
ρ_{LGS} = Density of Low-Gravity Solids

The density of water, low-gravity solids and mud are all known. If the volume of mud is 100% and the mud weight is known, the volume of the LGS can be determined. First, the volume of water must be solved for in the volume equation.

$$\%V_{Water} = 100\% - \%V_{LGS}$$

Then this equation must be substituted into the material balance.

$$100\%\ \rho_{Mud} = (100\% - \%V_{LGS})\ \rho_{Water} + \%V_{LGS}\ \rho_{LGS}$$

Solving for the percent volume of low-gravity solids the following equation is obtained:

$$\%V_{LGS} = 100\%\ \frac{(\rho_{Mud} - \rho_{Water})}{(\rho_{LGS} - \rho_{Water})}$$

UNWEIGHTED MUD

Problem: An unweighted freshwater mud has a density of 9.2 lb/gal. Determine the percent of low-gravity solids in the system.

$$\%V_{LGS} = 100 \times \frac{(\rho_{Mud} - \rho_{Water})}{(\rho_{LGS} - \rho_{Water})}$$

$$\%V_{LGS} = 100 \times \frac{(9.2 - 8.345)}{(21.7 - 8.345)} = 6.4\%$$

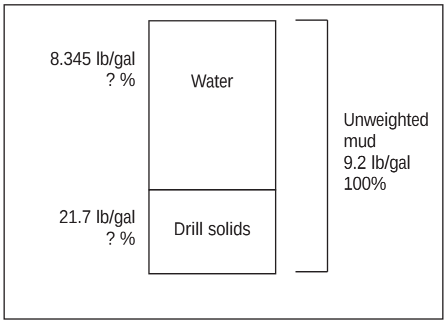


Figure 13: Unweighted mud diagram.

The equation is also valid for metric units. If this mud has a specific gravity of 1.10, what is the percent low-gravity solids?

$$\%V_{LGS} = 100 \text{ x } \frac{(\rho_{Mud} - \rho_{Water})}{(\rho_{LGS} - \rho_{Water})}$$

$$\%V_{LGS} = 100 \text{ x } \frac{(1.10 - 1.0)}{(2.6 - 1.0)} = 6.25\%$$

NOTE: For an unweighted system it is more accurate to use the above-mentioned equation instead of running a retort.

WEIGHTED MUD

The second case is a weighted system containing sodium chloride and oil. This material balance is one of the more complicated material balance evaluations encountered in drilling fluids engineering.

For this example, the following is given:

Mud weight	16.0 lb/gal
Chlorides	50,000 mg/l
Oil (%)	5 (7.0 lb/gal)
Retort water (%)	63
Weight material	M-I BAR (35.0 lb/gal)

A complete solids analysis can be performed with this information.

Step 1. Draw a component diagram.

Step 2. Determine the known and unknown variables and label the components. Use the appropriate density for the HGS, LGS and oil.

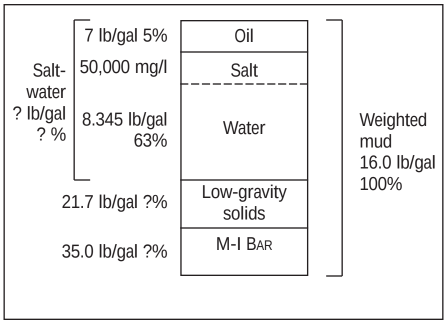


Figure 14: Weighted mud diagram.

Components	**ρ (lb/gal)**	**V (%)**
HGS	35.0	?
LGS	21.7	?
Oil	7.0	5%
Salt	?	?
Water	8.345	63%
Product	—	—
Mud	16.0	100%

Step 3. Write the material balance and volume equations.

$$V_{Mud}\,\rho_{Mud} = V_{HGS}\,\rho_{HGS} + V_{LGS}\,\rho_{LGS} + V_{SW}\,\rho_{SW} + V_{Oil}\,\rho_{Oil}$$

$$V_{Mud} = V_{HGS} + V_{LGS} + V_{SW} + V_{Oil} = 100\%$$

The volume of saltwater cannot be determined directly. The retort measures the quantity of distilled water in the mud sample (V_{Water}). The volume of salt (V_{Salt}) can be calculated after measuring the chloride concentration of the filtrate (saltwater).

The volume of saltwater is equal to the retort water volume plus the calculated salt volume:

$$V_{SW} = V_{Water} + V_{Salt}$$

The equations are changed to use these variables.

$$V_{Mud}\,\rho_{Mud} = V_{HGS}\,\rho_{HGS} + V_{LGS}\,\rho_{LGS} + (V_{Water} + V_{Salt})\,\rho_{SW} + V_{Oil}\,\rho_{Oil}$$

$$V_{Mud} = V_{HGS} + V_{LGS} + (V_{Water} + V_{Salt}) + V_{Oil} = 100\%$$

Step 4. Develop the corresponding equations to solve for the unknowns.

The density of the saltwater (P_{SW}) can be calculated from the chloride concentration. The following equation is a curve fit of density-to-chloride concentration for sodium chloride.

$$SG_{SW} = 1+1.166 \times 10^{-6} \times (\text{mg/l Cl}^-) - 8.375 \times 10^{-13} \times (\text{mg/l Cl}^-)^2 + 1.338 \times 10^{-18} \times (\text{mg/l Cl}^-)^3$$

$$SG_{SW} = 1+1.166 \times 10^{-6} \times (50{,}000) - 8.375 \times 10^{-13} \times (50{,}000)^2 + 1.338 \times 10^{-18} \times (50{,}000)^3 = 1.0564 \text{ kg/l}$$

$$\rho_{SW} \text{ (lb/gal)} = 1.0564 \times 8.345 \quad = 8.82 \text{ lb/gal}$$

The weight percent sodium chloride of the saltwater is calculated by the following expression:

$$\% \text{ NaCl (wt)} = \frac{\text{mg/l Cl}^- \times 1.65}{SG_{SW} \times 10{,}000}$$

$$\% \text{ NaCl (wt)} = \frac{50{,}000 \times 1.65}{1.0564 \times 10{,}000} = 7.81\%$$

The volume percent salt of the mud (V_{Salt}) can be calculated from the specific gravity and weight percent sodium chloride of the saltwater by the following equation:

$$V_{Salt} = V_{Water} \left[\left(\frac{100}{SG_{SW} \, (100 - \% \text{ NaCl (wt)})} \right) - 1 \right]$$

$$V_{Salt} = 63\% \left[\left(\frac{100}{1.0564 \, (100 - 7.81)} \right) - 1 \right] \qquad = 1.69\%$$

Frequently this salt concentration is reported in pounds per barrel using the following conversion:

$$\text{NaCl (lb/bbl)} = (V_{Water} + V_{Salt}) \times \frac{\text{mg/l Cl}^- \times 1.65}{10{,}000} \times \frac{3.5}{100}$$

$$\text{NaCl (lb/bbl)} = (63 + 1.69) \times \frac{50{,}000 \times 1.65}{10{,}000} \times \frac{3.5}{100} \qquad = 18.68 \text{ lb/bbl}$$

Step 5. Use the material balance and volume equations to solve for the remaining unknowns.

V_{HGS} and V_{LGS} are the only remaining unknowns. First the volume equation is solved for V_{LGS} in terms of V_{HGS} and substituted into the material balance equation to obtain:

$$V_{Mud}\,\rho_{Mud} = V_{HGS}\,\rho_{HGS} + V_{LGS}\,\rho_{LGS} + (V_{Water} + V_{Salt})\,\rho_{SW} + V_{Oil}\,\rho_{Oil}$$

$$V_{HGS}\,\rho_{HGS} = V_{Mud}\,\rho_{Mud} - (100 - V_{Water} - V_{Salt} - V_{Oil} - V_{HGS})\,\rho_{LGS} - (V_{Water} + V_{Salt})\rho_{SW} - V_{Oil}\,\rho_{Oil}$$

$$V_{HGS} = \frac{100\,\rho_{Mud} - (100 - V_{Water} - V_{Salt} - V_{Oil})\,\rho_{LGS} - (V_{Salt} + V_{Water})\,\rho_{SW} - V_{Oil}\,\rho_{Oil}}{\rho_{HGS} - \rho_{LGS}}$$

$$V_{HGS} = \frac{16 \times 100 - (100 - 63 - 1.69 - 5) \times 21.7 - (1.69 + 63) \times 8.8 - 7 \times 5}{(35 - 21.7)} = 25.41\%$$

This concentration is converted to lb/bbl units as follows:

$$HGS = \frac{V_{HGS}}{100} \times \rho_{HGS}$$

$$HGS\ (lb/bbl) = \frac{25.41\%}{100} \times (35\ lb/gal \times 42\ gal/bbl) \qquad = 373.5\ lb/bbl$$

Next, V_{LGS} can be determined using the volume equation:

$$V_{LGS} = 100\% - V_{Water} - V_{Salt} - V_{Oil} - V_{HGS}$$

$$V_{LGS} = 100\% - 63\% - 1.69\% - 5\% - 25.41\% \qquad = 4.9\%$$

This concentration is converted to lb/bbl units as follows:

$$LGS = \frac{V_{LGS}}{100} \times \rho_{LGS}$$

$$LGS\ (lb/bbl) = \frac{4.9\%}{100} \times (21.7\ lb/gal \times 42\ (gal/bbl)) \qquad = 44.7\ lb/bbl$$

A summary of the completed solids analysis is checked for volume and weight.

Volume (%)	
V_{H_20}	63
V_{OIL}	5
V_{SALT}	1.69
V_{HGS}	25.41
V_{LGS}	4.9
Total	**100.0**

Weight (lb/bbl)	
H_2O [0.63 x 350]	220.5
Oil [0.05 x 7 x 42]	14.7
NaCl	18.7
HGS	373.5
LGS	44.7
Total	**672.1**

$$\rho_{Mud}\ (lb/gal) = \frac{672.1}{42} = 16.0\ lb/gal$$

The bentonite concentration (V_{BENT}) and drill solids (V_{DS}) can be determined if the Cation Exchange Capacity (CEC) of the mud and drill solids is known (as measured by the Methylene Blue Test (MBT)).

The V_{LGS} are considered to be only drill solids and bentonite. The ratio (F) of the CEC of drill solids to the CEC of commercial bentonite is the fraction of equivalent bentonite in the drill solids. If the CEC is not known then a default average value of 1/9 or 0.1111 is used.

$$V_{LGS} = V_{BENT} + V_{DS}$$

$$MBT = V_{BENT} + F \times V_{DS}$$

The volume equation is solved for VDS and substituted into the second equation that reduces to the following expression in lb/bbl units:

$$Bentonite\ (lb/bbl) = \frac{MBT - (F \times LGS\ (lb/bbl))}{(1 - F)}$$

Continuing with the example, using an MBT for the mud of 25 lb/bbl, an MBT for the drill solids of 19.5 meq/100 g, and the CEC for commercial bentonite is 65 meq/100 g:

$$F = \frac{19.5}{65} = 0.30$$

$$Bentonite\ (lb/bbl) = \frac{25 - (0.3 \times 44.7)}{(1 - 0.3)} \qquad = 16.6\ lb/bbl$$

This concentration is converted to a percentage by:

$$V_{BENT} = \frac{\text{bentonite (lb/bbl)}}{9.1} = \frac{16.6}{9.1} = 1.82\%$$

The percent and lb/bbl drill solids are determined using the volume equation:

$$V_{DS} = V_{LGS} - V_{BENT}$$

$$V_{DS} = 4.9 - 1.82 \qquad = 3.08\%$$

Drill solids (lb/bbl) = LGS (lb/bbl) - bentonite (lb/bbl)
Drill solids (lb/bbl) = 44.7 lb/bbl - 16.6 lb/bbl = 28.1 lb/bbl

One measure used to judge the solids concentration is the drill-solids-to-bentonite ratio:

$$\text{DS/bentonite ratio} = \frac{V_{DS}}{V_{BENT}} = \frac{\text{DS (lb/bbl)}}{\text{bentonite (lb/bbl)}}$$

$$\text{DS/bentonite ratio} = \frac{3.07\%}{1.82\%} \text{ or } \frac{28.1 \text{ (lb/bbl)}}{16.6 \text{ (lb/bbl)}} = 1.69$$

Solids Calculation in Complex Brines

It becomes more and more common to use low-solids or completely solids-free systems to drill certain sections of a well. The main application of these systems is to drill the reservoir section where a minimized solids content provides exceptionally low formation damage. The density of those systems is not adjusted with solids, but instead with heavy brines, and normally only a small amount of soluble solids (calcium carbonate or sized salts) is added to build a thin filter cake for fluid-loss-control reasons.

Brine	**Maximum Density (lb/gal)**	**Maximum Density (kg/l)**
NaCl	10.0	1.20
$CaCl_2$	11.6	1.39
$CaCl_2$ /$CaBr_2$	15.6	1.87
KCl	9.6	1.16
NaBr	12.6	1.51
$CaBr_2$	15.1	1.81
$ZnBr_2$	19.2	2.30
NaCOOH	11.2	1.34
KCOOH	13.0	1.56
CsCOOH	19.5	2.34

NOTE: Do not use the above-mentioned densities without referencing the brine tables for freeze and crystallization points.

The previously described solids analysis do not apply when determining the drill solids content of these systems because of the complexity of salt systems using salts different from sodium chloride. For a solids calculation of a brine system, it is essential to determine the correct brine density and the correct mud weight. This sounds simple, but some polymer systems tend to entrap air, making it difficult to determine the correct mud weight even when using an electronic scale or pressurized mud balance.

NOTE: The following solids calculation only applies to systems containing LGS.

STEP 1: PROCEDURE TO DETERMINE MUD WEIGHT IN HIGH-VISCOSITY FLUIDS WITH ENTRAPPED AIR.

1) Put a 100-ml, calibrated volumetric flask on an electronic scale and zero it.
2) Weigh in 40 to 60 ml of drilling fluid and record as “Weight of Drilling Fluid (DF).”
3) Fill the flask with deionized water to the 100-ml mark and record as “Weight of Drilling Fluid (DF) + Water (W).” Swirl the flask lightly while filling with water to release air trapped in the fluid.
4) Calculate the mud weight as follows:

$$\rho_{\text{Mud}}\ (\text{kg/l}) = \frac{\text{Weight}_{\text{Drilling Fluid}}}{100 - \text{Weight}_{\text{Drilling Fluid + Water}} + \text{Weight}_{\text{Drilling Fluid}}}$$

Where:

$\text{ml (Water)} = \text{g(Water)} = \text{Weight}_{\text{Drilling Fluid + Water}} - \text{Weight}_{\text{Drilling Fluid}}$

$\text{Volume}_{\text{Drilling Fluid}} = 100 - \text{ml (water)}$

STEP 2: PROCEDURE TO DETERMINE BRINE DENSITY.

Collect at least 10 ml of API filtrate. Use a laboratory centrifuge to separate solids from clear brine in case of very low fluid loss. If the centrifuge does not produce a clear brine, use a micropore filter or try to flocculate polymers by raising the pH with NaOH crystals prior to using the centrifuge. If approximately 10 ml of clear brine are recovered, use pycnometer (special small calibrated volumetric flask) and electronic balance to determine brine density.

$$\text{Brine density} = \frac{\text{Weight}_{\text{Brine}}}{\text{Volume}_{\text{Brine}}}$$

To calculate the LGS content of the drilling fluid use mass balance.

$$V_{\text{LGS}} = 100\% \frac{(\rho_{\text{Mud}} - \rho_{\text{Brine}})}{(\rho_{\text{LGS}} - \rho_{\text{Brine}})}$$

NOTE: Apply material balance if the system contains non-aqueous fluids such as glycols or oil.

The Mud Report

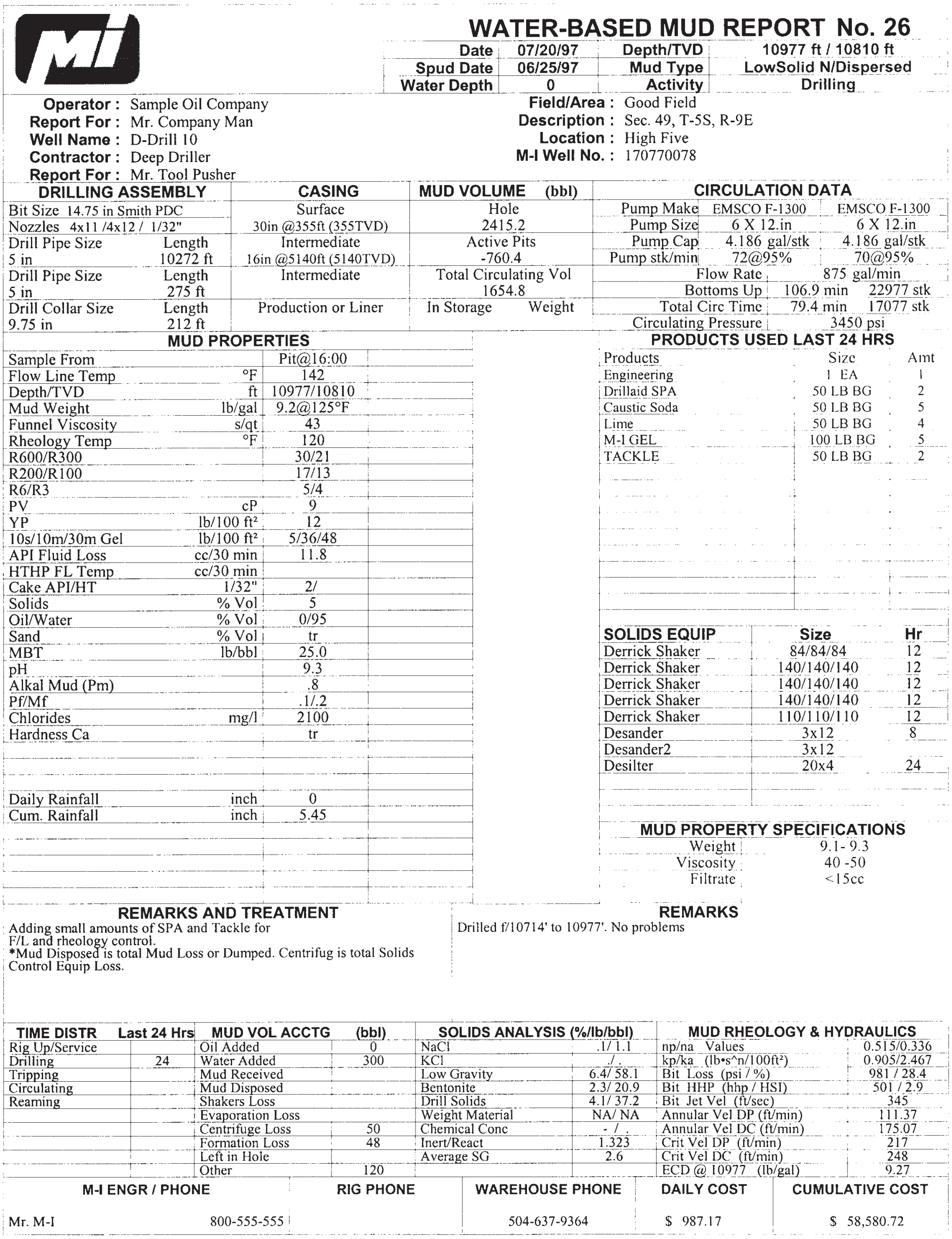
A permanent record should be made every time a mud engineer runs a mud check. The mud engineer's job is important and his responsibilities are great. Drilling equipment and the drilling operations are expensive. The crews, the tool pushers and management look to the mud engineer for direction and control of the most important thing that goes into a drilling operation — the drilling mud. To some extent, every service company that has anything to do with the well from spudding in to completion must have the help of the mud engineer and the mud report.

These reports should be made as complete and be as well done as possible. They are not only a permanent record of your service and responsibility to the company, but they are your principal contact with your own management. These days most rigs use computer programs for the reports, but still sometimes the mud report needs to be filled in manually (since they must be made in quintuplicate it is suggested that they be printed with a ballpoint pen). You will find an example of both types in the back of this chapter.

DISTRIBUTION OF DAILY MUD REPORT

The first copy of the daily mud report goes to the operating company. The second copy stays at the rig. Copy number three goes to your own district manager to be filed later in the division office. Copy number four is your personal copy and copy number five is an extra copy. If the operator wants an extra copy, give him copy number four and keep number five for your file. This copy should be retained in the engineer's active file until the well is completed and then transferred to his inactive file and filed under areas or companies. Thus, the longer an engineer remains in a territory the more valuable he can become to his own company and also the operating companies in his area.

When using computer programs, remember to keep a back-up of all your files at all times, especially on the rigsite where there is a good chance of computer failure.



WATER-BASED MUD REPORT No. 26

Date	07/20/97	**Depth/TVD**	10977 ft / 10810 ft
Spud Date	06/25/97	**Mud Type**	LowSolid N/Dispersed
Water Depth	0	**Activity**	Drilling

Operator : Sample Oil Company
Report For : Mr. Company Man
Well Name : D-Drill 10
Contractor : Deep Driller
Report For : Mr. Tool Pusher

Field/Area : Good Field
Description : Sec. 49, T-5S, R-9E
Location : High Five
M-I Well No. : 170770078

DRILLING ASSEMBLY

Bit Size 14.75 in Smith PDC	
Nozzles 4x11 /4x12 / 1/32"	
Drill Pipe Size	Length
5 in	10272 ft
Drill Pipe Size	Length
5 in	275 ft
Drill Collar Size	Length
9.75 in	212 ft

CASING

Surface
30in @355ft (355TVD)
Intermediate
16in @5140ft (5140TVD)
Intermediate
Production or Liner

MUD VOLUME (bbl)

Hole
2415.2
Active Pits
-760.4
Total Circulating Vol
1654.8
In Storage Weight

CIRCULATION DATA

Pump Make	EMSCO F-1300	EMSCO F-1300
Pump Size	6 X 12.in	6 X 12.in
Pump Cap	4.186 gal/stk	4.186 gal/stk
Pump stk/min	72@95%	70@95%
Flow Rate	875 gal/min	
Bottoms Up	106.9 min	22977 stk
Total Circ Time	79.4 min	17077 stk
Circulating Pressure	3450 psi	

MUD PROPERTIES

Sample From		Pit@16:00
Flow Line Temp	°F	142
Depth/TVD	ft	10977/10810
Mud Weight	lb/gal	9.2@125°F
Funnel Viscosity	s/qt	43
Rheology Temp	°F	120
R600/R300		30/21
R200/R100		17/13
R6/R3		5/4
PV	cP	9
YP	lb/100 ft²	12
10s/10m/30m Gel	lb/100 ft²	5/36/48
API Fluid Loss	cc/30 min	11.8
HTHP FL Temp	cc/30 min	
Cake API/HT	1/32"	2/
Solids	% Vol	5
Oil/Water	% Vol	0/95
Sand	% Vol	tr
MBT	lb/bbl	25.0
pH		9.3
Alkal Mud (Pm)		.8
Pf/Mf		.1/.2
Chlorides	mg/l	2100
Hardness Ca		tr
Daily Rainfall	inch	0
Cum. Rainfall	inch	5.45

PRODUCTS USED LAST 24 HRS

Products	Size	Amt
Engineering	1 EA	1
Drillaid SPA	50 LB BG	2
Caustic Soda	50 LB BG	5
Lime	50 LB BG	4
M-I GEL	100 LB BG	5
TACKLE	50 LB BG	2

SOLIDS EQUIP	**Size**	**Hr**
Derrick Shaker	84/84/84	12
Derrick Shaker	140/140/140	12
Derrick Shaker	140/140/140	12
Derrick Shaker	140/140/140	12
Derrick Shaker	110/110/110	12
Desander	3x12	8
Desander2	3x12	
Desilter	20x4	24

MUD PROPERTY SPECIFICATIONS

Weight	9.1- 9.3
Viscosity	40 -50
Filtrate	<15cc

REMARKS AND TREATMENT

Adding small amounts of SPA and Tackle for
F/L and rheology control.
*Mud Disposed is total Mud Loss or Dumped. Centrifug is total Solids
Control Equip Loss.

REMARKS

Drilled f/10714' to 10977'. No problems

TIME DISTR	**Last 24 Hrs**
Rig Up/Service	
Drilling	24
Tripping	
Circulating	
Reaming	

MUD VOL ACCTG	**(bbl)**
Oil Added	0
Water Added	300
Mud Received	
Mud Disposed	
Shakers Loss	
Evaporation Loss	
Centrifuge Loss	50
Formation Loss	48
Left in Hole	
Other	120

SOLIDS ANALYSIS (%/lb/bbl)	
NaCl	.1/ 1.1
KCl	./ .
Low Gravity	6.4/ 58.1
Bentonite	2.3/ 20.9
Drill Solids	4.1/ 37.2
Weight Material	NA/ NA
Chemical Conc	- / .
Inert/React	1.323
Average SG	2.6

MUD RHEOLOGY & HYDRAULICS	
np/na Values	0.515/0.336
kp/ka (lb•s^n/100ft²)	0.905/2.467
Bit Loss (psi / %)	981 / 28.4
Bit HHP (hhp / HSI)	501 / 2.9
Bit Jet Vel (ft/sec)	345
Annular Vel DP (ft/min)	111.37
Annular Vel DC (ft/min)	175.07
Crit Vel DP (ft/min)	217
Crit Vel DC (ft/min)	248
ECD @ 10977 (lb/gal)	9.27

M-I ENGR / PHONE		**RIG PHONE**	**WAREHOUSE PHONE**	**DAILY COST**	**CUMULATIVE COST**
Mr. M-I	800-555-555		504-637-9364	$ 987.17	$ 58,580.72

Figure 15: Typical mud report.

Engineering Calculations

	U.S. (ρ in lb/gal)	**Metric (ρ in kg/l)**
Hydrostatic pressure	$\Delta P\ (\text{psi}) = \text{TVD (ft)} \times \rho_{\text{Mud}} \times 0.052$	$\Delta P\ (\text{psi}) = \dfrac{\text{TVD (m)} \times \rho_{\text{Mud}}}{10.2}$
Kill-mud weight	$\rho_{\text{Kill mud}}\ (\text{lb/gal}) = \rho_{\text{Mud}} + \dfrac{\text{SIDPP (psi)}}{0.052 \times \text{TVD (ft)}}$	$\rho_{\text{Kill mud}}\ (\text{kg/l}) = \rho_{\text{Mud}} + \dfrac{\text{SIDPP (bar)} \times 10.2}{\text{TVD (m)}}$
Fracture-mud weight	$\rho_{\text{Fracture}}\ (\text{lb/gal}) = \rho_{\text{Mud leak-off test}} + \dfrac{\text{leak-off pressure (psi)}}{0.052 \times \text{TVD (ft)}}$	$\rho_{\text{Fracture}}\ (\text{kg/l}) = \rho_{\text{Mud leak-off test}} + \dfrac{\text{leak-off pressure (bar)} \times 10.2}{\text{TVD (m)}}$
Fracture-pressure limit	$\Delta P\ (\text{psi}) = \text{TVD}_{\text{Casing}}\ (\text{ft}) \times \ldots$ $0.052 \times (\rho_{\text{Fracture}} - \rho_{\text{Mud}})$	$\Delta P\ (\text{bar}) = \dfrac{\text{TVD}_{\text{Casing}}\ (\text{m})}{10.2} \times (\rho_{\text{Fracture}} - \rho_{\text{Mud}})$
Maximum Allowable Surface Pressure (MASP)	$\Delta P\ (\text{psi}) = \text{TVD}_{\text{Casing Shoe}}\ (\text{ft}) \times \ldots$ $0.052 \times (\rho_{\text{Fracture}} - \rho_{\text{Mud}})$	$\Delta P\ (\text{bar}) = \dfrac{\text{TVD}_{\text{Casing Shoe}}\ (\text{m})}{10.2} \times (\rho_{\text{Fracture}} - \rho_{\text{Mud}})$
Weight-up formula (general)	lb/gal weighting material = $\rho_{\text{Weighting Material}} \times 42\ \dfrac{(\rho_{\text{desired}} - \rho_{\text{initial}})}{(\rho_{\text{Weighting Material}} - \rho_{\text{desired}})}$	kg/m^3 weighting material = $\rho_{\text{Weighting Material}} \times 1{,}000\ \dfrac{(\rho_{\text{desired}} - \rho_{\text{initial}})}{(\rho_{\text{Weighting Material}} - \rho_{\text{desired}})}$
Weight-up formula (barite)	$\text{lb/gal barite} = 1{,}470\ \dfrac{(\rho_{\text{desired}} - \rho_{\text{initial}})}{(35.0\ \text{lb/gal} - \rho_{\text{desired}})}$	$\text{kg/m}^3\ \text{barite} = 4{,}200\ \dfrac{(\rho_{\text{desired}} - \rho_{\text{initial}})}{(4.2\ \text{kg/l} - \rho_{\text{desired}})}$
Volume of rectangular tank	Volume (bbl) = length (ft) x width (ft) x … height (ft) x 0.1781	Volume (m^3) = length (m) x width (m) x height (m)
Volume increase	$\text{Volume (bbl)} = \dfrac{\text{sacks of barite}}{14.70}$	$\text{Volume } (\text{m}^3) = \dfrac{\text{metric tons of barite}}{4.2}$
LGS for freshwater, unweighted mud	$\text{Vol \% LGS} = 100\ \dfrac{(\rho_{\text{Mud}} - \rho_{\text{Water}})}{(\rho_{\text{LGS}} - \rho_{\text{Water}})}$	$\text{Vol \% LGS} = 100\ \dfrac{(\rho_{\text{Mud}} - \rho_{\text{Water}})}{(\rho_{\text{LGS}} - \rho_{\text{Water}})}$
Blending of muds	$\rho_{\text{Final}} = \dfrac{(V_{\text{Mud1}}\rho_{\text{Mud1}} + V_{\text{Mud2}}\rho_{\text{Mud2}})}{(V_{\text{Mud1}} + V_{\text{Mud2}})}$	$\rho_{\text{Final}} = \dfrac{(V_{\text{Mud1}}\rho_{\text{Mud1}} + V_{\text{Mud2}}\rho_{\text{Mud2}})}{(V_{\text{Mud1}} + V_{\text{Mud2}})}$
Annular velocity	AV (ft/min) = $\dfrac{\text{pump output (bbl/min)}}{\text{annular volume (bbl/ft)}} = \dfrac{24.5 \times \text{gpm}}{D_h^2 - D_p^2}$	AV (m/min) = $\dfrac{\text{pump output (l/min)}}{\text{annular volume (l/m)}} = \dfrac{\text{l/min} \times 1.974}{D_h^2 - D_p^2}$
Bottoms up	BU (min) = $\dfrac{\text{annular volume (bbl/ft)}}{\text{pump output (bbl/min)}} = \dfrac{D_h^2 - D_p^2}{1{,}029 \times \text{bbl/min}}$	BU (min) = $\dfrac{\text{annular volume (l/m)}}{\text{pump output (l/min)}} = \dfrac{D_h^2 - D_p^2}{1.974 \times \text{l/min}}$
Material balance	$V_{\text{total}}\rho_{\text{total}} = \sum_{1}^{n} V_{\text{Components}}\rho_{\text{Components}} =$ $V_1\rho_1 + V_2\rho_2 + V_3\rho_3 + \ldots + V_n\rho_n$	$V_{\text{total}}\rho_{\text{total}} = \sum_{1}^{n} V_{\text{Components}}\rho_{\text{Components}} =$ $V_1\rho_1 + V_2\rho_2 + V_3\rho_3 + \ldots + V_n\rho_n$
Volume balance	$V_{\text{total}} = \sum_{1}^{n} V_{\text{Components}} = V_1 + V_2 + V_3 + \ldots + V_n$	$V_{\text{total}} = \sum_{1}^{n} V_{\text{Components}} = V_1 + V_2 + V_3 + \ldots + V_n$
Hole volume	$V_{\text{Well}}\ (\text{bbl}) = \dfrac{\text{ID}_{\text{Well}}^2\ (\text{in.})}{1{,}029} \times \text{L(ft)}$	$V_{\text{Well}}\ (\text{m}^3) = \dfrac{\text{ID}_{\text{Well}}^2\ (\text{mm})}{1{,}273{,}000} \times \text{L(m)}$ $V_{\text{Well}}\ (\text{m}^3) = \dfrac{\text{ID}_{\text{Well}}^2\ (\text{in.})}{1{,}974} \times \text{L(m)}$
Pipe capacity	$V_{\text{Pipe}}\ (\text{bbl}) = \dfrac{\text{ID}_{\text{Pipe}}^2\ (\text{in.})}{1{,}029} \times \text{L(ft)}$	$V_{\text{Pipe}}\ (\text{m}^3) = \dfrac{\text{ID}_{\text{Pipe}}^2\ (\text{mm})}{1{,}273{,}000} \times \text{L(m)}$ $V_{\text{Pipe}}\ (\text{m}^3) = \dfrac{\text{ID}_{\text{Pipe}}^2\ (\text{in.})}{1{,}974} \times \text{L(m)}$
Annular volume	$V_{\text{Annulus}}\ (\text{bbl}) = \dfrac{\text{ID}_{\text{Well}}^2\ (\text{in.}) - \text{OD}_{\text{DS}}^2\ (\text{in.})}{1{,}029} \times \text{L(ft)}$	$V_{\text{Annulus}}\ (\text{m}^3) = \dfrac{\text{ID}_{\text{Well}}^2\ (\text{mm}) - \text{OD}_{\text{DS}}^2\ (\text{mm})}{1{,}273{,}000} \times \text{L(m)}$ $V_{\text{Annulus}}\ (\text{m}^3) = \dfrac{\text{ID}_{\text{Well}}^2\ (\text{in.}) - \text{OD}_{\text{DS}}^2\ (\text{in.})}{1{,}974} \times \text{L(m)}$

	U.S. (ρ in lb/gal)	Metric (ρ in kg/l)
Pump output (triplex pump)	$V_{\text{Pump Output}}$ (bbl/stk) = $\frac{ID_{\text{Liner}}^2 \text{ (in.)} - L \text{ (in.)} \times Eff \text{ (decimal)}}{4{,}116}$	$V_{\text{Pump Output}}$ (l/stk) = $\frac{ID_{\text{Liner}}^2 \text{ (in.)} - L \text{ (in.)} \times Eff \text{ (decimal)}}{25.905}$ $V_{\text{Pump Output}}$ (l/stk) = $\frac{ID_{\text{Liner}}^2 \text{ (mm)} - L \text{ (mm)} \times Eff \text{ (decimal)}}{424{,}333}$
Circulation time	Total circulation time (min) = $\frac{V_{\text{System}}}{V_{\text{Pump Output}}}$	Total circulation time (min) = $\frac{V_{\text{System}}}{V_{\text{Pump Output}}}$
Circulation strokes	Total circulation strokes = total circulation time (min) x pump rate (stk/min)	Total circulation strokes = total circulation time (min) x pump rate (stk/min)
Bottoms-up (strokes)	Bottoms-up strokes = bottoms-up time (min) x pump rate (stk/min)	Bottoms-up strokes = bottoms-up time (min) x pump rate (stk/min)
Hole circulation (time)	Hole cycle time (min) = $\frac{V_{\text{Hole}} - \text{Displacement}_{DS}}{V_{\text{Pump Output}}}$	Hole cycle time (min) = $\frac{V_{\text{Hole}} - \text{Displacement}_{DS}}{V_{\text{Pump Output}}}$
Hole circulation (strokes)	Hole cycle strokes = Hole cycle time (min) x pump rate (stk/min)	Hole cycle strokes = Hole cycle time (min) x pump rate (stk/min)

Table 9: Summary of formulas.

Salt Tables

Weight (%)	Density (kg/l)	Density (lb/gal)	Cl^- (mg/l)	Na^+ (mg/l)	NaCl (lb/bbl)	Water (bbl)	Cryst. Pt. (°F)	Water Activity
1	1.005	8.38	6,127	3,973	3.5	0.995	30.9	0.994
2	1.013	8.44	12,254	7,946	7.1	0.992	29.9	0.989
3	1.020	8.50	18,563	12,037	10.7	0.989	28.8	0.983
4	1.027	8.56	24,932	16,168	14.4	0.986	27.7	0.977
5	1.034	8.62	31,363	20,337	18.1	0.982	26.5	0.970
6	1.041	8.68	37,914	24,586	21.9	0.979	25.3	0.964
7	1.049	8.75	44,526	28,874	25.7	0.975	24.1	0.957
8	1.056	8.81	51,260	33,240	29.6	0.971	22.9	0.950
9	1.063	8.87	58,054	37,646	33.5	0.968	21.5	0.943
10	1.071	8.93	64,970	42,130	37.5	0.964	20.2	0.935
11	1.078	8.99	71,946	46,654	41.5	0.960	18.8	0.927
12	1.086	9.05	79,044	51,256	45.6	0.955	17.3	0.919
13	1.093	9.12	86,202	55,898	49.7	0.951	15.7	0.911
14	1.101	9.18	93,481	60,619	53.9	0.947	14.1	0.902
15	1.109	9.24	100,882	65,418	58.2	0.942	12.4	0.892
16	1.116	9.31	108,344	70,256	62.5	0.938	10.6	0.883
17	1.124	9.37	115,927	75,173	66.9	0.933	8.7	0.872
18	1.132	9.44	123,570	80,130	71.3	0.928	6.7	0.862
19	1.140	9.51	131,396	85,204	75.8	0.923	4.6	0.851
20	1.148	9.57	139,282	90,318	80.4	0.918	2.4	0.839
21	1.156	9.64	147,229	95,471	84.9	0.913	0.0	0.827
22	1.164	9.71	155,357	100,743	89.6	0.908	-2.5	0.815
23	1.172	9.78	163,547	106,053	94.4	0.903	-5.2	0.802
24	1.180	9.84	171,858	111,442	99.2	0.897	1.4	0.788
25	1.189	9.91	180,290	116,910	104.0	0.892	14.7	0.774
26	1.197	9.98	188,843	122,457	109.0	0.886	27.9	0.759

% volume salt = 100 x (1.0 - bbl water).

Table 10: Sodium chloride.

Properties based on 20°C and 100% purity.

Weight (%)	Density (kg/l)	Density (lb/gal)	Cl^- (mg/l)	Ca^{2+} (mg/l)	$CaCl_2$ (lb/bbl)	Water (bbl)	Cryst. Pt. (°F)	Water Activity
1	1.007	8.39	6,453	3,647	3.5	0.996	31.2	0.994
2	1.015	8.46	12,969	7,331	7.1	0.995	30.4	0.989
3	1.023	8.53	19,613	11,087	10.7	0.993	29.6	0.985
4	1.032	8.60	26,385	14,915	14.5	0.990	28.7	0.980
5	1.040	8.67	33,221	18,779	18.2	0.988	27.8	0.975
6	1.049	8.75	40,185	22,715	22.0	0.986	26.7	0.971
7	1.057	8.82	47,277	26,723	25.9	0.983	25.6	0.965
8	1.066	8.89	54,496	30,804	29.9	0.981	24.3	0.960
9	1.075	8.96	61,779	34,921	33.8	0.978	22.9	0.954
10	1.084	9.04	69,190	39,110	37.9	0.975	21.5	0.948
11	1.092	9.11	76,793	43,407	42.1	0.972	19.9	0.940
12	1.101	9.19	84,459	47,741	46.3	0.969	18.1	0.932
13	1.111	9.26	92,253	52,147	50.5	0.966	16.3	0.924
14	1.120	9.34	100,175	56,625	54.9	0.963	14.3	0.914
15	1.129	9.42	108,225	61,175	59.3	0.960	12.2	0.904
16	1.139	9.50	116,403	65,797	63.8	0.957	9.9	0.892
17	1.148	9.58	124,708	70,492	68.3	0.953	7.4	0.880
18	1.158	9.66	133,141	75,259	72.9	0.950	4.8	0.867
19	1.168	9.74	141,766	80,134	77.7	0.946	1.9	0.852
20	1.178	9.82	150,455	85,045	82.4	0.942	-0.9	0.837
22	1.198	9.99	168,343	95,157	92.2	0.934	-7.1	0.804
24	1.218	10.16	186,743	105,557	102.3	0.926	-13.5	0.767
26	1.239	10.33	205,781	116,319	112.7	0.917	-21.5	0.726
28	1.260	10.51	225,395	127,405	123.5	0.907	-31.2	0.683
30	1.282	10.69	245,647	138,853	134.6	0.897	-47.7	0.637
32	1.304	10.87	266,474	150,626	146.0	0.886	-19.5	0.590
34	1.326	11.06	288,004	162,796	157.8	0.875	4.3	0.541
36	1.349	11.25	310,237	175,363	170.0	0.863	24.1	0.492
38	1.372	11.44	333,109	188,291	182.5	0.851	42.1	0.443
40	1.396	11.64	356,683	201,617	195.4	0.837	55.9	0.395

% volume salt = 100 x (1.0 - bbl water).

Table 11: Calcium chloride.

Properties based on 20°C and 100% purity.

Density (lb/gal at 60°F)	Water (bbl)	100% NaCl (lb/bbl)	94 - 97% $CaCl_2$ (lb/bbl)	Cryst. Pt. (°F)
10.1	0.887	88	29	-4
10.2	0.875	70	52	-10
10.3	0.875	54	72	-15
10.4	0.876	41	89	-21
10.5	0.871	32	104	-26
10.6	0.868	25	116	-32
10.7	0.866	20	126	-38
10.8	0.864	16	135	-42
10.9	0.862	13	144	-24
11.0	0.859	10	151	-12
11.1	0.854	8	159	0

Table 12: Sodium-calcium chloride blends.

Weight (%)	Density (kg/l)	Density (lb/gal)	Cl^- (mg/l)	K^+ (mg/l)	KCl (lb/bbl)	Water (bbl)	Cryst. Pt. (°F)	Water Activity
1	1.005	8.38	4,756	5,244	3.5	0.995	31.2	0.996
2	1.011	8.43	9,606	10,594	7.1	0.991	30.3	0.991
3	1.017	8.49	14,504	15,996	10.7	0.987	29.5	0.987
4	1.024	8.54	19,498	21,502	14.4	0.983	28.7	0.982
5	1.030	8.59	24,491	27,009	18.0	0.979	27.8	0.977
6	1.037	8.65	29,579	32,621	21.8	0.975	27.0	0.973
7	1.043	8.70	34,715	38,285	25.6	0.970	26.1	0.968
8	1.050	8.76	39,947	44,053	29.4	0.966	25.2	0.963
9	1.057	8.81	45,225	49,875	33.3	0.962	24.3	0.958
10	1.063	8.87	50,551	55,749	37.2	0.957	23.4	0.953
11	1.070	8.92	55,973	61,727	41.2	0.952	22.4	0.947
12	1.077	8.98	61,442	67,758	45.2	0.948	21.4	0.942
13	1.084	9.04	67,006	73,894	49.3	0.943	20.4	0.936
14	1.091	9.09	72,617	80,083	53.4	0.938	20.0	0.930
15	1.097	9.15	78,276	86,324	57.6	0.933	18.5	0.925
16	1.104	9.21	84,030	92,670	61.8	0.928	17.0	0.918
17	1.111	9.27	89,832	99,068	66.1	0.922	16.0	0.912
18	1.119	9.33	95,729	105,571	70.5	0.917	15.0	0.906
19	1.126	9.39	101,721	112,179	74.9	0.912	14.0	0.899
20	1.133	9.45	107,760	118,840	79.3	0.906	13.0	0.892
22	1.147	9.57	120,030	132,370	88.3	0.895	34.0	0.878
24	1.162	9.69	132,632	146,268	97.6	0.883	59.0	0.862

% volume salt = 100 x (1.0 - bbl water).

Table 13: Potassium chloride.

Properties based on 20°C and 100% purity.

Weight (%)	Density (kg/l)	Density (lb/gal)	Cl^- (mg/l)	Mg^{2+} (mg/l)	$MgCl_2$ (lb/bbl)	Water (bbl)	Cryst. Pt. (°F)	Water Activity
1	1.006	8.39	7,492	2,568	3.54	0.9962	31.1	0.995
2	1.014	8.46	15,106	5,178	7.21	0.9941	30.1	0.990
3	1.023	8.52	22,842	7,830	10.98	0.9919	29	0.984
4	1.031	8.59	30,703	10,524	14.88	0.9897	27.9	0.978
5	1.039	8.66	38,696	13,264	18.91	0.9874	26.6	0.972
6	1.048	8.74	46,814	16,047	23.07	0.985	24.3	0.964
7	1.056	8.81	55,060	18,873	27.35	0.9825	22.3	0.957
8	1.065	8.88	63,444	21,747	31.77	0.9799	21.5	0.948
9	1.074	8.95	71,957	24,665	36.33	0.9772	19.6	0.939
10	1.083	9.02	80,608	27,631	41.03	0.9744	18	0.929
12	1.101	9.17	98,329	33,705	50.88	0.9685	14.4	0.906
14	1.119	9.33	116,635	39,980	61.36	0.9623	5.8	0.879
16	1.137	9.48	135,477	46,439	72.44	0.9552	-1.9	0.848
18	1.155	9.63	154,838	53,075	84.11	0.9474	-13	0.812
20	1.174	9.79	174,856	59,937	96.54	0.9394	-27.8	0.772
22	1.194	9.95	195,553	67,031	109.77	0.9312	-18.5	0.727
24	1.214	10.12	216,940	74,362	123.84	0.9226	-11.8	0.677
26	1.235	10.29	239,006	81,926	138.75	0.9136	-5	0.624
28	1.256	10.47	261,748	89,722	154.52	0.9039	1.3	0.567
30	1.276	10.64	285,091	97,723	171.09	0.8934	2.4	0.507

% volume salt = 100 x (1.0 - bbl water).

Table 14: Magnesium chloride.

Properties based on 20°C and 100% purity.

Weight (%)	Density (kg/l)	Density (lb/gal)	Cl^- (mg/l)	NH_4^+ (mg/l)	NH_4Cl (lb/bbl)	Water (bbl)	Cryst. Pt. (°F)
1	1.001	8.35	6,066	3,934	3.5	0.991	30.9
2	1.005	8.38	12,193	7,907	7.0	0.984	29.7
3	1.008	8.40	18,320	11,880	10.6	0.977	28.6
4	1.011	8.43	24,508	15,892	14.1	0.970	27.4
5	1.014	8.46	30,756	19,944	17.7	0.963	26.2
6	1.017	8.48	37,004	23,996	21.4	0.956	24.9
7	1.020	8.51	43,313	28,087	25.0	0.948	23.6
8	1.023	8.53	49,622	32,178	28.6	0.941	22.3
9	1.026	8.55	55,992	36,308	32.3	0.933	20.9
10	1.029	8.58	62,422	40,478	36.0	0.926	19.5
11	1.032	8.60	68,852	44,648	39.7	0.918	18.0
12	1.034	8.63	75,282	48,818	43.4	0.910	16.5
13	1.037	8.65	81,773	53,027	47.2	0.902	15.0
14	1.040	8.67	88,325	57,275	51.0	0.895	—
15	1.043	8.70	94,877	61,523	54.7	0.887	11.0
16	1.046	8.72	101,489	65,811	58.6	0.878	—
17	1.049	8.74	108,101	70,099	62.4	0.870	—
18	1.051	8.77	114,774	74,426	66.2	0.862	—
19	1.054	8.79	121,508	78,792	70.1	0.854	—
20	1.057	8.81	128,180	83,120	74.0	0.845	—
22	1.062	8.86	141,769	91,931	81.8	0.828	—
24	1.067	8.90	155,418	100,782	89.7	0.811	31.0

% volume salt = 100 x (1.0 - bbl water).

Table 15: Ammonium chloride.

Properties based on 20°C and 100% purity.

Weight (%)	Density (kg/l)	Density (lb/gal)	K^+ (mg/l)	SO_4^{2-} (mg/l)	K_2SO_4 (lb/bbl)	Water (bbl)	Cryst. Pt. (°F)
0.5	1.004	8.37	2,244	2,756	1.8	0.997	31.8
1.0	1.008	8.41	4,532	5,568	3.5	0.996	31.5
1.5	1.012	8.44	6,821	8,379	5.3	0.995	31.9
2.0	1.016	8.47	9,110	11,190	7.1	0.994	31.1
2.5	1.020	8.51	11,443	14,057	8.9	0.993	31.9
3.0	1.024	8.54	13,776	16,924	10.7	0.992	31.9
3.5	1.028	8.58	16,110	19,790	12.6	0.991	31.8
4.0	1.032	8.61	18,488	22,712	14.4	0.989	31.8
4.5	1.037	8.64	20,911	25,689	16.3	0.988	30.1
5.0	1.041	8.68	23,290	28,610	18.2	0.987	29.9
5.5	1.045	8.71	25,758	31,642	20.1	0.986	—
6.0	1.049	8.75	28,181	34,619	22.0	0.984	—
6.5	1.053	8.78	30,649	37,651	23.9	0.983	—
7.0	1.057	8.82	33,162	40,738	25.9	0.981	—
7.5	1.061	8.85	35,675	43,825	27.8	0.980	—
8.0	1.066	8.89	38,188	46,912	29.8	0.979	—
8.5	1.070	8.92	40,746	50,054	31.8	0.977	—
9.0	1.074	8.96	43,304	53,196	33.8	0.976	—
9.5	1.078	8.99	45,907	56,393	35.8	0.974	—
10.0	1.083	9.03	48,509	59,591	37.8	0.973	—

% volume salt = 100 x (1.0 - bbl water).

Table 16: Potassium sulfate.

Properties based on 20°C and 100% purity.

Weight (%)	Density (kg/l)	Density (lb/gal)	K^+ (mg/l)	$C_2H_3O_2^-$ (mg/l)	$KC_2H_3O_2$ (lb/bbl)	Water (bbl)	Cryst. Pt. (°F)	Water Activity
1	1.004	8.37	3,984	6,016	3.5	0.994	32.0	0.99
2	1.009	8.41	7,967	12,033	7.0	0.989	31.5	0.98
3	1.014	8.45	11,951	18,049	10.5	0.984	31.0	0.97
4	1.019	8.49	15,935	24,065	14.0	0.979	—	0.96
5	1.024	8.54	19,918	30,082	17.5	0.974	—	0.95
6	1.029	8.58	25,040	37,817	22.0	0.966	—	0.94
7	1.034	8.62	29,593	44,693	26.0	0.960	—	0.93
8	1.040	8.66	34,146	51,568	30.0	0.954	—	0.92
9	1.045	8.71	39,837	60,163	35.0	0.945	—	0.91
10	1.050	8.75	44,390	67,039	39.0	0.938	—	0.90
11	1.055	8.79	48,943	73,915	43.0	0.932	—	0.89
12	1.060	8.83	54,634	82,509	48.0	0.923	—	0.88
13	1.065	8.88	59,186	89,385	52.0	0.917	—	0.87
14	1.070	8.92	64,877	97,980	57.0	0.907	—	0.86
15	1.076	8.96	70,568	106,574	62.0	0.898	—	0.85
16	1.081	9.01	76,259	115,169	67.0	0.889	—	0.84
17	1.086	9.05	81,950	123,764	72.0	0.880	—	0.83
18	1.091	9.10	87,641	132,359	77.0	0.871	—	0.82
19	1.097	9.14	93,332	140,953	82.0	0.863	—	0.81
20	1.102	9.19	100,162	151,267	88.0	0.851	—	0.80
21	1.086	9.05	105,853	159,862	93.0	0.820	—	0.79
22	1.113	9.28	112,682	170,175	99.0	0.830	—	0.78
23	1.119	9.32	119,511	180,489	105.0	0.819	—	0.77
24	1.124	9.37	126,340	190,803	111.0	0.807	1.0	0.76
25	1.129	9.41	133,169	201,116	117	0.795	—	0.75

% volume salt = 100 x (1.0 - bbl water).

Table 17: K-52™ (potassium acetate).

Properties based on 20°C and 100% purity.

From \ To	Salt (% wt)	Chloride (% wt)	Salt (ppm)	Chloride (ppm)	Salt (mg/l)	Chloride (mg/l)
Salt (% wt)	1.0	x 1/factor	x 10^4	x 1/factor x 10^4	x 10^4 x SG	x 1/factor x 10^4 x SG
Cl^- (% wt)	x factor	1.0	x factor x 10^4	x 10^4	x factor x 10^4 x SG	x 10^4 x SG
Salt (ppm)	x 10^{-4}	x 1/factor x 10^{-4}	1.0	x 1/factor	x SG	x 1/factor x SG
Cl^- (ppm)	x factor x 10^{-4}	x 10^{-4}	x factor	1.0	x factor x SG	x SG
Salt (mg/l)	x 10^{-4} x 1/SG	x 1/factor x 10^{-4} x 1/SG	x 1 / SG	x 1/factor x 1/SG	1.0	x 1/factor
Cl^- (mg/l)	x factor x 10^{-4} x 1/SG	x 10^{-4}	x factor x 1/SG	x 1/SG	x factor	1.0

Salt	Factor	1/Factor
$CaCl_2$	1.5642	0.6393
NaCl	1.6488	0.6065
KCl	2.103	0.4755

Example: 384,000 mg/l $CaCl_2$ = (384,000)(0.6393)(1/1.282) = 191,000 ppm Cl^-.

All titration results are in mg/l.

Table 18: Concentration conversions for brines.