Material Balance

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TRAINING ON DESIGN, OPERATION, AND INTEGRITY OF GEOTHERMAL WELL

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MATERIAL BALANCE

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Material Balance

- Material balance concepts are useful to the mud engineer for solving many field problems that can be represented as simple mathematical relationships. Applications for the material balance method are:
  - Weight-Up
  - Dilution
  - Mixing Two Fluids

Material Balance (Cont’d)

- Many of the formulas commonly used in the oil field were derived from material balance equations. Maintaining consistent units is the key to setting up and solving material balance equations. The general material balance equation is written as follows:
- $V_1D_1 + V_2D_2 + V_3D_3 + etc. = V_FD_F$
- V = Volume ; D = Density; V_F = Final Volume ;
- D_F = Final Density

Weight-Up of Water-Based Muds

- No Volume Increase

	$V_I MW_I$ *Old Fluid*	$V_{WM} D_{WM}$ *Weight Material*	$V_F MW_F$ *New Fluid*
System Volume, bbl	500	X	500
System Density, lb/gal	9.5	35.0	10.0

Weight-Up of Water-Based Muds

Nomenclature	
Mud Density, lb/gal	MW
Initial	MW_I
Final	MW_F
Initial Volume, bbl	V_I
Final Volume, bbl	V_F

Weight-Up of Water-Based Muds (Cont’d)

- The material balance approach means that to increase the density of 500 bbl of a 9.5 lb/gal fluid to10.0 lb/gal, without increasing the total volume of fluid, the problem can be represented as follows:

Old Fluid	+	Weight Material	=	New Fluid
$V_I MW_I$	+	$V_{WM} D_{WM}$	=	$V_F MW_F$

Weight-Up of Water-Based Muds (Cont’d)

Nomenclature	
Mud Density, lb/gal	MW
Initial	MW_I
Final	MW_F
Density of Weight Material, lb/gal	D_{WM}
Density of Water, lb/gal	D_W

Weight-Up of Water-Based Muds (Cont'd)

- Each of these materials will be represented in terms of the product density and volume. Since it is not known how much barite (weight material) is needed, the volume of barite is represented by (x). The volume of 9.5 lb/gal fluid is represented by (500 - x).
- The new fluid is 10.0 lb/gal, and the final volume is 500 bbls. The starting fluid volume is the 500 bbl initial fluid volume minus the volume of barite which will be added.

Weight-Up of Water-Based Muds (Cont'd)

Old Fluid	+	Barite	=	New Fluid
(500 bbl-x) (9.5 lb/gal)	+	(x) (35.0 lb/gal)	=	(500 bbl) (10.0 lb/gal)

- Solving the equation for x:

$$
\begin{aligned}
(V_I)(MW_I) + (V_{WM})(D_{WM}) &= (V_F)(M_{WF}) \\
(500 - x)(9.5) + (x)(35.0) &= (500)(10.0) \\
4750 - 9.5x + 35.0x &= 5000 \\
25.5x &= 250 \\
x &= 9.8 \text{ bbl of barite}
\end{aligned}
$$

Weight-Up of Water-Based Muds (Cont'd)

- Then,

$$500 - x = 500 - 9.8 = 490.2 \text{ bbl of mud}$$

- Thus, 9.8 bbl of old mud must be jetted and 9.8 bbl of barite added. One barrel of barite equals 1470 pounds. Therefore, 9.8 bbl of barite equals 1470 (9.8) equals 14,406 lb. Add 14,406 lb of barite after jetting 9.8 bbl of mud.

Weight-Up of Water-Based Muds (Cont'd)

- The amount of barite required can further be simplified as sacks of barite required to add to the mud system as follows:

$$\frac{14,406 \text{ lb barite}}{(100 \text{ lb/sx})} = 144.065 \text{ sx barite}(144 \text{ sacks})$$

Weight-Up of Water-Based Muds

- Volume Increase

	$V_l MW_l$ *Old Fluid*	$V_{WM} D_{WM}$ *Weight Material*	$V_F MW_F$ *New Fluid*
System Volume, bbl	500	X	--
System Density, lb/gal	9.5	35.0	10.0

Weight-Up of Water-Based Muds (Cont'd)

- Again, using the material balance equation:

Old Fluid	+	Weight Material	=	New Fluid
$V_I MW_I$	+	$V_{WM} D_{WM}$	=	$V_F MW_F$

Weight-Up of Water-Based Muds (Cont'd)

Nomenclature	
Mud Density, lb/gal	MW
Initial	MW_I
Final	MW_F
Density of Weight Material, lb/gal	D_{WM}
Density of Water, lb/gal	D_W

Weight-Up of Water-Based Muds (Cont’d)

- Substitute the product density and volume for each term in the equation. Since it is not known how much barite will be needed, the volume of barite is represented by (x). The volume of the 10.0 lb/gal fluid is equal to the **Old Fluid** volume plus the volume of barite added.

Weight-Up of Water-Based Muds (Cont'd)

- Thus the **New Fluid** volume equals: 500 + x.

Old Fluid	**+**	**Barite**	**=**	**New Fluid**
(500 bbl) (9.5 lb/gal)	+	(x) (35.0 lb/gal)	=	(500 bbl + x) (10.0 lb/gal)

$$
\begin{aligned}
(V_I)(MW_I) + (V_{WM})(D_{WM}) &= (V_F)(M_{WF}) \\
(500)(9.5) + (35.0)(x) &= (500 + x)(10.0) \\
4750 + 35x &= 5000 + 10x \\
25.5x &= 250 \\
x &= 10 \text{ bbl of barite}
\end{aligned}
$$

Weight-Up of Water-Based Muds (Cont'd)

- Then

$$500 + x = 500 + 10 = 510 \text{ bbl of new fluid}$$

Dilution of Water-Based Muds

- Density Reduction/No Volume Increase

	$V_l MW_l$ Old Fluid	$V_{WM} D_{WM}$ Weight Material	$V_F MW_F$ New Fluid
System Volume, bbl	500	X	500
System Density, lb/gal	9.5	8.33	9.0

Dilution of Water-Based Muds (Cont'd)

- Again, using the material balance equation:

Old Fluid	+	Weight Material	=	New Fluid
$V_I MW_I$	+	$V_{WM} D_{WM}$	=	$V_F MW_F$

Weight-Up of Water-Based Muds (Cont'd)

Nomenclature	
Mud Density, lb/gal	MW
Initial	MW_I
Final	MW_F
Density of Weight Material, lb/gal	D_{WM}
Density of Water, lb/gal	D_W

Weight-Up of Water-Based Muds (Cont'd)

- Substitute the product density and volume for each term in the equation. Since it is not known how much water will be needed, the volume of water is represented by (x).

Old Fluid	+	Fresh Water	=	New Fluid
(500 bbl - x) (9.5 lb/gal)	+	(x) (8.33 lb/gal)	=	(500 bbl) (9.0 lb/gal)

Weight-Up of Water-Based Muds (Cont'd)

- **Solving the equation for x:**

$$
\begin{aligned}
(V_I)(MW_I) + (V_W)(D_W) &= (V_F)(MW_F) \\
(500 - x)(9.5) + (x)(8.33) &= (500)(9.0) \\
4750 - 9.5x + 8.33x &= 4500 \\
-1.17x &= -250 \\
x &= 214 \text{ bbl of Fresh Water}
\end{aligned}
$$

- Thus, 214 bbl of the **Old Fluid** must be jetted and 214 bbl of **Fresh Water** must be added to have 500 bbl of 9.0 lb/gal fluid.

Dilution of Water-Based Muds

- Density Reduction - Volume Increase

	$V_l MW_l$ *Old Fluid*	$V_{WM} D_{WM}$ *Weight Material*	$V_F MW_F$ *New Fluid*
System Volume, bbl	500	X	--
System Density, lb/gal	9.5	8.33	9.0

Dilution of Water-Based Muds (Cont'd)

- Again, using the material balance equation:

Old Fluid	+	Weight Material	=	New Fluid
$V_I MW_I$	+	$V_{WM} D_{WM}$	=	$V_F MW_F$

Dilution of Water-Based Muds (Cont'd)

-

Nomenclature	
Mud Density, lb/gal	MW
Initial	MW_I
Final	MW_F
Density of Weight Material, lb/gal	D_{WM}
Density of Water, lb/gal	D_W

Dilution of Water-Based Muds (Cont'd)

- Substitute the product density and volume for each term in the equation. Since it is not known how much water will be needed, the volume of water is represented by (x). The volume of the 9 lb/gal fluid is equal to the Old Fluid volume plus the volume of water added. Thus, the New Fluid volume equals 500 + x.

Dilution of Water-Based Muds (Cont’d)

- Thus, the new fluid volume equals 500 + x.

Old Fluid	+	Fresh Water	=	New Fluid
(500 bbl) (9.5 lb/gal)	+	(x) (8.33 lb/gal)	=	(500 bbl + x) (9.0 lb/gal)

Dilution of Water-Based Muds (Cont'd)

- **Solving the equation for x:**

$$(V_I)(MW_I) + (V_W)(D_W) = (V_F)(MW_F)$$

$$(500)(9.5) + (x)(8.33) = (500 + x)(9.0)$$

$$4750 + 8.33x = 4500 + 9.0x$$

$$-0.67x = -250$$

$$x = 373 \text{ bbl of water}$$

Mixing Two Fluids

- Mixing two fluids to achieve specific results is another application for material balance concepts. Simple equations can be utilized for calculating desired parameters. The following examples should help to clarify and demonstrate the use of the material balance approach.

Mixing Two Fluids (Cont'd)

- **Example Calculations**

A circulating system of **1000 bbl** has a density of **12.0 lb/gal.** There are **300 bbl of 10.0 lb/gal** mud in storage on the rig site. How many barrels of **10.0 lb/gal** mud are needed to reduce the fluid density to **11.6 lb/gal**?

Mixing Two Fluids (Cont'd)

- Where

$$(V_I)(MW_I) + (V_S)(MW_S) = (V_F)(MW_F)$$

MW_F	=	Final Mud Density
MW_I	=	Initial Mud Density
MW_S	=	Stored Mud Density
V_S	=	Volume Stored Mud to Add
V_F	=	Final Volume
V_I	=	Initial Volume

Mixing Two Fluids (Cont'd)

	$V_l MW_l$ *Old Fluid*	$V_s MW_s$ *Weight Material*	$V_F MW_F$ *New Fluid*
Volume, bbl	1000	X	---
Density, lb/gal	12.0	10.0	11.6

Mixing Two Fluids (Cont'd)

- This problem can be solved by representing everything in terms of material balance. In other words, the total desired weight is equal to that of the combined systems. The equation is set up as follows:

Old Fluid + Stored Fluid = New Fluid

Or

$$(V_I)(MW_I) + (V_S)(MW_S) = (V_F)(MW_F)$$

Mixing Two Fluids (Cont'd)

- Solving the equation for X:

$$
\begin{aligned}
(V_I)(MW_I) + (V_S)(MW_S) &= (V_F)(MW_F) \\
(1000)(12.0) + (x)(10.0) &= (1000 + x)(11.6) \\
12,000 + 10.0x &= 11,600 + 11.6x \\
-1.6x &= -400 \\
x &= 250 \text{ bbl of} 10.0 \text{ lb/gal mud}
\end{aligned}
$$

Mixing Two Fluids (Cont’d)

- **Example Calculations**

How much volume of **16.0 lb/gal** mud with **0 volume % drill solids (VADA)** must be added to the old 16.0 lb/gal lb fluid with **8 volume % drill solids** to reduce the drill solids in the resulting new **16 lb/gal fluid to 5 volume %?**

Mixing Two Fluids (Cont'd)

- Given

	(V_I,%SOL_I) Old Fluid	(V_A,%SOL_A) Weight Mat'l	(V_F,%SOL_F) New Fluid
Volume, bbl	1200	X	--
Density, lb/gal	16.0	16.0	16.0
Drill Solids, %	8	0	5

Mixing Two Fluids (Cont'd)

- Where

$$V_I\,(\%SOL_I) + V_A\,(\%SOL_A) = V_F\,(\%SOL_F)$$

V_A = Volume of mud to add

$\%SOL_A$ = Percent solids in fluid being added

Mixing Two Fluids (Cont'd)

- Where

	Old Fluid	+	Mud to Add	=	New Fluid
Or					
	$V_I\ (\%SOL_I)$	+	$V_A\ (\%SOL_A)$	=	$V_F\ (\%SOL_F)$

Mixing Two Fluids (Cont'd)

- Solving the equation for X:

$$
\begin{aligned}
(V_I)(\%SOL_I) + (V_A)(\%SOL_A) &= (V_F)(\%SOL_F) \\
(1200)(0.08) + (x)(0) &= (1200 + x)(0.05) \\
96 + 0x &= 60 + 0.05x \\
0.05x &= 36 \\
x &= 720 \text{ bbl new } 16.0 \text{ lb/gal mud}
\end{aligned}
$$

Mixing Two Fluids (Cont'd)

- Checking the result:

8% = 0.08 fraction drill solids

Therefore, 8% of 1200 bbl = (.08) (1200)= 96 bbl of drill solids
The total resulting barrels of mud is 1200 + 720 = 1920 bbl

Therefore:

$$\frac{96\ \text{bbl}}{1920\ \text{bbl}} = 0.05 \text{ or} 5 \text{ volume } \%$$