Dave Cormack

An Introduction to Well Control Calculations for Drilling Operations

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The cover photograph was taken by the author on the Amoco North West Hutton platform during a trip into the hole around 1984. It shows the view down to the rig floor from the monkey board level.

Printed on acid-free paper

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Acknowledgement

Thanks to Douglas Adams for the words that kick the whole thing off (or was it Corporal Jones?)

Thanks to drilling people the world over for the inspiration. You can still make it all the way in this game if you put the work in and here's hoping this book helps a bit.

Thanks to E.S.T. and The Penguin Café Orchestra for providing the bulk of (but not all) the background noise during the writing phase – check them both out.

and…

…to Cal for everything else - especially Anna, Alexander, Louise & Maria - xxxx forever.

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About the Author

Dave Cormack has worked in the drilling industry out of Aberdeen, Scotland since 1983. He has worked on over thirty drilling rigs, platforms or MODU's either as a member of the drill crew or in a training capacity. Since 1991 he has been exclusively involved in training drilling personnel either on the rig, in the classroom or in a management capacity worldwide. He served a three-year term on the Board of Directors of the International Well Control Forum and was one of the contributing authors to the Well Control chapter in the recently revised International Association of Drilling Contractors definitive Drilling Manual. He has been involved in well control training on every continent on earth bar the polar ones, has published two SPE papers and made presentations on training at global drilling conferences. Dave still teaches well control regularly to both international certification standards and also runs courses globally, training the next wave of well control assessors for IWCF. He is passionate about helping students through their two yearly well control school and firmly believes that a solid grasp of calculation skills frees them up to concentrate on learning well control.

CHAPTER 1
GETTING A HANDLE ON CALCULATIONS

This chapter of the book has been written to give you the calculation skills you need to master to be able to perform the calculations you will learn in the other three chapters. It also gives you some tips as to the best way to go about studying including how to use this book. The calculation topics covered are:

- Introduction to your calculator
- Fractions and decimals
- Squaring a number
- Percentages
- Rounding your answers
- Symbols used in calculations
- Figuring out the order of a calculation
- Formulas
- Converting units

Once you have worked your way through all the topics and have mastered the skill there is a final chapter test for you to tackle.

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DON'T PANIC

Welcome to An Introduction to Well Control Calculations for drilling operations.

The four chapters in this book will show you how to do some of the calculations you will need to perform through your career in the drilling industry, and in particular those you will need when you attend well control school. The book has been written by a roughneck so they can be understood by roughnecks. However, toolpushers and engineers may also find them helpful!

For many drilling people their first well control school will also be the first time they have done any calculations since high school – and it can be daunting. Your first well control school is a big deal – it's the moment you make that step into supervision and you should enjoy the experience. You are there to learn well control and not worry about the calculations.

The book you are just about to work through will help prepare you so that when you do attend your first well control school you go in confident, knowing that the calculations will not scare you. You will have the skills you need and you will be able to use these skills. This will allow you to get the best out of your well control school.

But…………… and there is always a but……………. **You** will only be able to use the skills if **you** put some work into learning the skills. It's the same thing as learning any other skill such as playing the guitar or cooking (yes, cooking!).

You have to put the time in getting the basics nailed first.

Take your time. **Do not skip anything.** **Read every word.**

Do every calculation.

This book has been written specifically to help you learn drilling calculations. They have been written in bite-size chunks (regular bites though, not roughneck ones!) so they are easy to read, easy to understand and easy to work through.

Each bite-size chunk, or lesson, has been written so you have the whole lesson to view. There will never be a need to turn the page to finish a lesson. Where appropriate, a lesson will have some worked examples to take you through the stages of a calculation.

A number of lessons will make up a subject. A full list of the subjects for each chapter can be found on the contents page at the start of the chapter. Throughout the book there are plenty of examples for you to try – make sure you do all of them. Worked answers are given over the page, but don't look at them until you have tried the questions first.

At the end of each chapter there is a test on everything you have learned. Do the test. Worked answers are given but again, take the test before you look at the answers.

Once you have finished this chapter you will be ready to move on to the next one which looks at volume calculations. Once you have finished all four chapters – and done so honestly – you will be able to attend well control school confident in your own ability to do the calculations. Hey, you may even be able to help out some of the toolpushers and engineers on the course!

A final warning. Maths can become addictive. Once you understand what to do and how to do it you may find yourself wanting to do more and more. You have been warned!

THINGS YOU WILL NEED

First up and also the most important thing you will need in order to get through this book successfully is the right attitude......and you cannot buy that in a store. You have to decide right now that you want to do this and that you are willing to put in the effort in order to succeed.

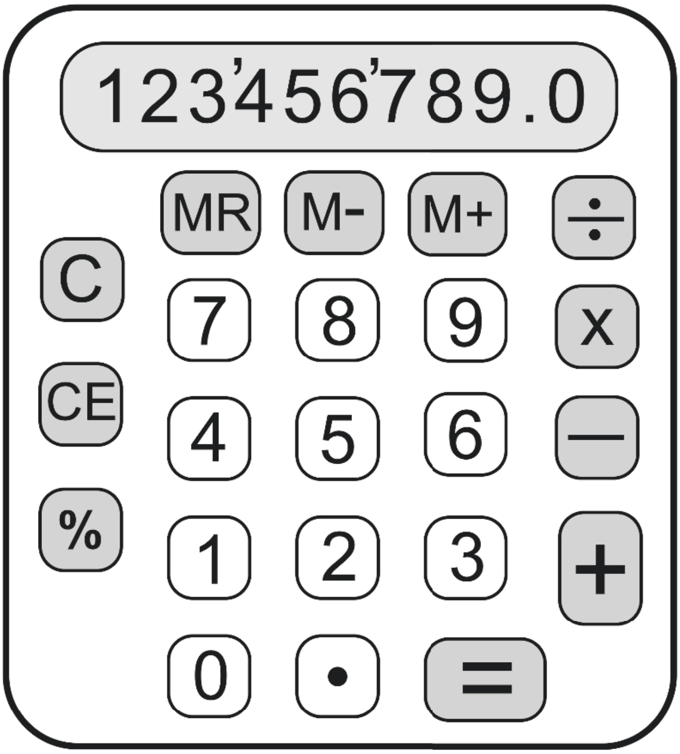
Next up you will need a calculator – a roughneck's calculator and not an engineer's one! A roughneck's calculator has big buttons, a big display and doesn't try to do too many things at the same time! Engineers' calculators do all sorts of fancy tricks and calculations but sometimes they also require a separate instruction book to teach you how to work them. We don't have the time to do that here!

This book has been designed to give you an understanding of calculations and how to do them. This is best done with a basic calculator, otherwise you may become too dependent on the technology. You often hear people say "Hey it works – who cares how?" Well, we want you to understand how it works.

If you don't yet have a calculator, or even if you do and it isn't a roughneck's calculator, then you will need to go out and buy one. A roughnecks' calculator should not cost you too much – around the cost of a burger & fries or a beer at your local drinking hole is an approximate guide. You should be able to pick one up pretty much anywhere really (maybe not at the bar though!) The main things to look for are:

- BIG buttons (or keys) – more room for fingers means less chance of mistakes
- A BIG display that shows at least 8 numbers but ideally shows 9, or perhaps even 10
- A basic memory function – this is usually in the form of three keys with "M+", "M-" and "MR" or "MRC" or similar on them.
- A percentage key "%" can also be useful but is not absolutely necessary.

The ideal calculator should look something like the one shown on the facing page.



When you are buying your calculator you should also pick up some pencils (along with a sharpener if they are the wooden type) and some blank paper – get a pad about the same size as this workbook.

Other things that may make life easier but are not totally essential include:

- A folder to keep your work in – the envelope type is best but you could use a ring binder (you will need to buy hole-punched paper if you get a ring binder)
- An eraser – mistakes can happen
- A ruler – sometimes it helps to do a drawing
- Coloured pencils or pens – they can help with drawings and sometimes even with the different stages of a calculation

Once you have all your equipment together you are ready to start planning when, where and how you are going to work through this book.

SETTING THE LEARNING HABIT

Now that you have this book, the right attitude, your calculator, pencil and paper it is almost time to make a start on the studying……..but not quite. The final thing you need to help you succeed is a bit of a plan as to when, where and how long you are going to study.

WHEN?

Are you going to study when you are off shift on the rig or are you going to study on leave time? Or perhaps you want to keep up the momentum once you have started and study both on and off the rig?

There is no correct answer but whatever you decide you should try your hardest to stick with your plan. It is all too easy to say that you'll give it a miss just this once but catch up tomorrow. You know only too well that you won't.

Next you need to decide when exactly you will do your studying. If you are on the rig then it is probably best immediately after you knock off shift. Get cleaned up, have something to eat then get stuck in. If you leave it too long after your shift has finished then you will end up drifting into other activities and before you know it you'll be tired and ready for bed.

On the other hand, you may decide that you will get up early each day and put an hour in before you go out on shift. This may work well for you if you are a morning person as you are likely to be fresher then and thinking clearly. If you do decide to go this route then pay attention to how you feel during your shift.

If you notice that you are feeling more tired than usual towards the end of your shift then you should think about going back to your regular work routine. Your first concern has to be your safety, the safety of your workmates and the quality of work you put in during your shift. If you find this is affected by you getting up early to study, then stop getting up early!

If you have decided that you are going to study during your leave then decide what the best time of day for you will be. If you have kids at school then it is probably best to get the morning school run out the way before starting, and you should stop before the afternoon school run. You may well have other regular things that you do during the day in your leave time so you should schedule a time for studying that does not get in the way of them. Do not put too many excuses in place to stop you from studying though!

For most people mornings will be the best time to study but for others the afternoon or evening will be better for any number of reasons. Only you can tell. You should also decide if you are going to study each day, only weekdays or every other day.

No matter if you have decided to study on the rig, on leave or a combination; mornings, afternoons or evenings; weekdays, weekends or every day you need to make every effort to stick with your plan. You are more likely to stick with your plan if it is written down. Use the table below to decide when you are going to study and write your plan down.

Drilling Calculations Study Plan – When?		
Rig Time/Leave/Both	Days I will study	Time I will study

WHERE?

Next you will have to find a good place to study. You are going to spend quite a bit of time studying so it is important that you choose a suitable place that will help with your learning and not hinder it.

You will need to find somewhere peaceful without too much noise or other distractions that could disturb you. If you are on the rig then your cabin may be a good place. Perhaps the rig has a study room you can go to?

If you are studying at home you may have a home office – this would be ideal. The dining or kitchen table is also a good surface.

Wherever you choose to study, try to avoid having too much background noise or through traffic. Switch the television and radio off. Ignore the phone.

You should work at a desk or table that is at a comfortable height for you. Your chair needs to be comfortable enough for you to be able to sit in it for extended periods (but not too comfortable that you fall asleep in it!).

There should be enough space on the table for you to be able to spread things out a bit. You should have this workbook open in front of you so you can read it easily with enough room to be able to work through calculations on your paper at the same time. Everything should be on the table and within easy reach.

Wherever you choose to study you need good lighting. Natural light is best but this will not always be possible (in fact, if it is night time then moonlight, while natural, is far from favourable!). You should use lighting that does not cast a shadow over your workbooks as this will be distracting, difficult to work through and may lead to tiredness. Use a good overhead light and supplement this with a desk lamp to eliminate shadows if needed.

Spend a little bit of time thinking about where you are going to study. The closer you can get to the ideal environment the better, but ultimately you will have to go with what you have available - so no excuses just because the chair was wrong!

HOW LONG?

The final part of your study plan that needs figuring out is how long are you are going to study for at a time?

If you are studying on the rig when off shift then the longest you will realistically have available to you will be around two hours per day. If you are going to study for this long then take a break about halfway through. Go stretch your legs or get a cup of tea. Do something that gets you out of your seat for a short break but keep it to a short break and not a derrickman's tea break!

If you are going to study on field break then you may be able to put in longer periods – particularly during the day. Once again, it is important to take regular breaks away from the books.

If you decide you will spend a whole day studying then you will need to take a meal break. This should be a slightly longer break (still not derrickman's lunch-break length though!) and if possible you should try to get outside for some fresh air.

The minimum length of time you spend studying should be around the hour mark. If you spend much less than this each time you study then you may find you spend too much time going over old stuff and not enough time on new stuff. This may cause you to become disillusioned and want to give up.

Posture is important while you are studying. You are going to spend longish periods of time sitting at a desk reading, writing and doing calculations. Every now and again you should sit up straight in your chair (or even stand up), have a stretch and take some deep breaths. Your brain needs oxygen to work properly and the best way to get oxygen to your brain is to take some deep breaths. Sounds new age hippy but it works – honest!

HOW TO USE THIS BOOK

This book has been written with you in mind. It has been developed for roughnecks and other drilling people, not for academics.

The language used is clear throughout - there are no fancy big words just to look sagacious. That means smart by the way!

The book is broken up into sections, subjects and lessons.

A subject may run to several pages. A lesson will never run to more than two pages, and some are only one page long.

The book has been designed so that when it is sitting open on the table you will always have an entire lesson to view. You will never have to turn the page to finish a lesson.

Throughout the book there are worked examples of some of the calculations. They are there to show you how the calculation is performed. Work through the calculation on your own calculator as you are reading the example.

There are also regular example questions for you to try. All questions come with fully worked out answers (usually over the page, but sometimes on the same page).

Try the calculations yourself before looking at the answers. You have nothing to gain by looking at the answers first.

Two different text styles have been used throughout this book. The one you are reading just now is the main style used to explain things and for setting questions.

This is the other style - used for worked examples and answers. This style will be used to show the workings of a calculation.

Write all calculations down clearly and work them through in stages as you are shown in each lesson. The more clearly and neatly you write the numbers down the more likely you are to understand what stage of a calculation you are at.

Make sure you also write down the final answer.

Keep different questions apart. Either draw a line under a calculation when you have completed it or use a new page.

Number or label calculations so when you go back and review things you know what you are looking at.

If you are not sure what a lesson is telling you go back to the beginning of the lesson and start again. Remember, you never have to turn the page to finish a lesson.

If that still does not help you may need to think about going back a few lessons or even to the start of the subject.

If you find you are still struggling to understand something it may be you have studied too long in a particular session. Take a break and come back to it or call it a day and start again next day.

There is a final test at the end of each chapter. It is there so you can check you understand everything. No-one will ever know how well you did in it.

Do it properly and under test conditions.

Before you try the test have a quick look through all the subjects first as a bit of a refresher.

When you sit the test, do not look back at how to do a calculation - try it yourself.

There are fully worked out answers following the test. They are there hopefully to let you know that you got everything correct and that you got the answers using the calculation skills you have learned.

They will also show you where you went wrong should you get any wrong.

In order to get the best out of this book make sure you:

Take your time. **Do not skip anything.** **Read every word.**

Do every calculation.

INTRODUCTION TO YOUR CALCULATOR

Before you get stuck in to the calculations it is probably best if we take a few minutes to introduce you to your calculator. All calculators work pretty much the same way (except the fancy engineer's ones which are a rule unto themselves!) so this introduction will be based on the assumption that your calculator is like the one opposite.

The calculator consists of a number of buttons, or **keys** as we will call them from here on, and a display. There may be some more keys than those shown, such as the "ON" key for instance! We are just going to look at those shown as they are really the only ones you will need to get you through pretty much any well control calculation you are likely to come across.

So what have you got on your calculator?

First up, the bit at the top is the "Display". This will show you numbers as you key them in and the final answer to your calculation when you hit the "Equals" key. It will also show you a running total for a calculation if it has more than one stage (more about this later).

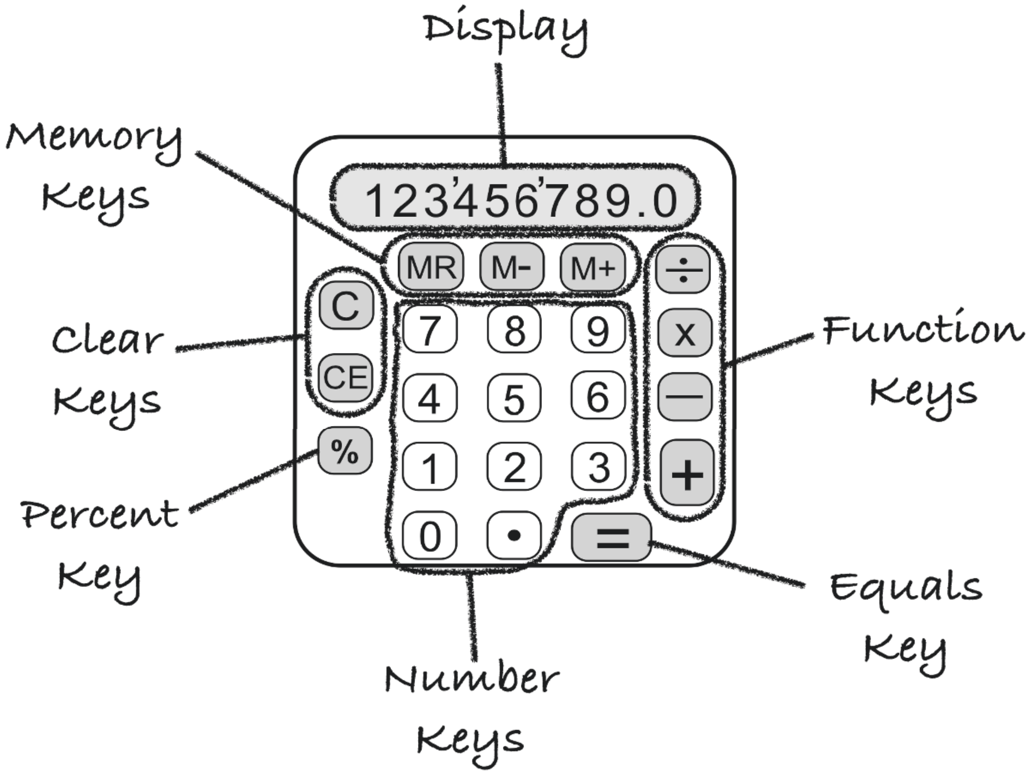
The "Number Keys" (which include the decimal point) are used to input the numbers required in the calculation.

The "Function Keys" tell the calculator whether you are going to add, subtract, multiply or divide. These are entered between the numbers you wish to do the calculation on.

The "Equals Key" is used to get the final answer to a calculation.

There are normally two "Clear Keys" on most calculators and they are shown with a "C" and a "CE". The "C" key is the "Clear" key and clears the display and any calculation that is taking place or has taken place. This key is sometimes also the "ON" key. The "CE" key is the "Clear Entry" key and is used to clear the last entry you made. This can be useful in the middle of a long calculation if you have made a mistake entering a number, as it will only clear that entry and not the whole calculation.

The "Percent Key" can be used to do several calculations based on percentages.



The "Memory Keys" can be used to add numbers to or subtract numbers from one that is stored in the memory. We will only use it to store a number in the memory that we want to use further on in a complex calculation (more about this later).

Some of the keys on your calculator may be slightly different to those shown (for instance "MR" can sometimes be "MRC", "RM" or "RMC" and you sometimes get an extra key to cancel the memory, "MC") but they will do the same things as described. If they are labelled differently then don't panic, just be aware of this fact as you work through these books.

Your calculator should have come with an instruction leaflet or booklet. These can be a little confusing to understand sometimes so in the next few pages we will have a look at how to make your calculator work and what happens when you key in certain things.

GETTING STARTED WITH THE CALCULATOR

Let’s start with a few basic calculations and see what happens. First up though you need to switch the calculator on (switch yours on now) and when you do this you will notice that the display shows zero.

0.

Notice the decimal point after the zero. Your calculator only works in decimals. We will look at decimals later. The calculator will automatically put the decimal point in at the end of a number unless you enter it otherwise.

As you key numbers in, the display fills from the right-hand side with the numbers as you enter them. Try entering the number 250 and watch what happens. The display will look like this when you are finished:

250.

Let’s now multiply the 250 by 4 and see what happens in the display. When you press (or “hit”) the multiply key (x) you will notice that the display continues to show:

250.

…and when you hit the number four key (4) it changes to:

4.

To finish the calculation you need to hit the equals key (=) and the display will show you the final answer of:

1’000.

Note the appearance of the comma (’) between the one (1) and the first zero (0). This is to indicate thousands. A comma will automatically be put in every three numbers to indicate thousands, millions and billions (one thousand million). Have a look at the picture of a calculator on the previous page to see this. The comma may be at the top of the display as I have shown or it may be at the bottom where you would place it if you were writing numbers of a thousand or more.

Let's see what happens if there is more than one stage to a calculation. We will look at adding three numbers together say, 9,800 + 645 + 360.

The first thing you need to do is clear the calculator – do this by hitting the clear key (C). You will see that the display returns to zero. **It is important that you clear the calculator before starting any calculation.**

Action	Display Shows
Enter 9800	9'800.
Note that the comma to indicate thousands has automatically been entered by the calculator, as has the decimal point at the end.	
Hit plus key (+)	9'800.
Note that the display has not changed.	
Enter 645	645.
Hit plus key (+)	10'445.
Note that the calculator has added up the first two numbers and that the display is now showing the running total. Your calculator will do this at each stage throughout a long calculation.	
Enter 360	360.
Hit equals key (=)	10'805.
When you hit the equals key the display shows you the final answer to the calculation.	

What you have just done is a calculation to work out the total length of the drill string if you have 9,800 feet of regular drill pipe, 645 feet of hevi weight drill pipe and 360 feet of drill collars.

THE DECIMAL POINT

So far we have looked at whole numbers. Many well control calculations require you to use numbers that are not whole or are less than one. A pounds per gallon (ppg) mud weight could be given as 11.3 ppg. We also regularly use the constant 0.052.

Let's see what happens when you enter them into your calculator.

First up, clear the calculator so the display shows zero. Next enter the 11.3 and the display will show you:

11.3

Note that the decimal point is no longer at the end but is in its proper place – the calculator moves it as you input a number. We are going to multiply the mud weight of 11.3 ppg by the constant 0.052, so hit the multiply key (x) and the display still shows:

11.3

We will now enter the 0.052 You can do this either by hitting all the numbers as shown or, because the number is less than one, you can simply enter .052 Whatever you do the display will show:

0.052

To get the final answer hit the equals key (=) as before and the display changes to:

0.5876

Note that as the answer is less than one the calculator shows a zero before the decimal point. What you have just done is work out the pressure gradient in psi per foot (psi/ft) of 11.3 ppg mud. This topic will be explained in the third chapter which looks at pressure calculations.

Let’s now see what happens when we use the decimal point in a more complex calculation. Do not worry about what the calculation means or how it works at the moment, as this will be explained later.

<table>
<tr><td colspan="2">Calculation: (350 ÷ 0.052 ÷ 8,350) + 12.4</td></tr>
<tr><th>Action</th><th>Display Shows</th></tr>
<tr><td>Hit clear (C)</td><td>0.</td></tr>
<tr><td>Enter 350</td><td>350.</td></tr>
<tr><td>Hit divide key (÷)</td><td>350.</td></tr>
<tr><td>Enter 0.052</td><td>0.052</td></tr>
<tr><td>Hit divide key (÷)</td><td>6’730.76923</td></tr>
<tr><td colspan="2">The calculator has done the first calculation and the display is showing the running total.</td></tr>
<tr><td>Enter 8350</td><td>8’350.</td></tr>
<tr><td>Hit plus key (+)</td><td>0.806080147</td></tr>
<tr><td colspan="2">The calculator has now done the second calculation and the display is showing the running total.</td></tr>
<tr><td>Enter 12.4</td><td>12.4</td></tr>
<tr><td>Hit equals key (=)</td><td>13.20608014</td></tr>
<tr><td colspan="2">When you hit the equals key the display shows you the answer to the calculation. If the answer is not exact then the display will show as many decimal points as it has available to it. This display has ten characters.</td></tr>
</table>

This calculation has just worked out a mud weight that we would normally call 13.2 ppg. We will look at rounding rules later in this chapter.

USING THE MEMORY FUNCTION

Sometimes you will come across a calculation that requires you to go through several stages before you get to the answer. For instance:

$$(130 + 12) - (4 \times 27)$$

Here you must subtract the answer to the second part (4×27) from the answer to $(130 + 12)$. Now, you could do this by writing the answer to each stage down on a sheet of paper then doing the subtraction. We will look at this method later on in this book.

Your calculator comes with a memory function that we are going to use to store one answer so we can use it later on. Let's see how it works for the calculation above. Follow this explanation on your calculator.

The first thing you need to work out is which answer do you need to store in the memory? As a general rule of thumb it will be the second one. In this case the answer to (4 x 27). When you do this in your calculator (remember to clear it first) the answer in your display should be:

To store this in the calculator's memory hit the memory plus key (M+). You will see a small M in the display when you do this.

This M is letting you know that you have a number stored in the memory. Hit clear and you will see:

Note that while the main display has returned to zero the small M is still showing. You have not cleared the memory. If you now do the first calculation (130 + 12) and hit equals (=) the display will show:

Again, note that the small M is still there.

Now we have the answer to both calculations. The answer to the first calculation is showing in the display and the answer to the second calculation is stored in the memory. It is now time to do the subtraction, so hit subtract (-). The display does not change:

To retrieve (or recall) the number stored in the memory hit the memory recall key (MR) and the display will now show:

To finish off the calculation hit equals (=) and the display shows the final answer of:

Note the small M is still there. You still have 108 stored in the memory and you can leave it there and use it for more calculations if you need to. Simply hit memory recall (MR) any time you want to use it.

In this case, however, we are finished with 108 and we want to get it out of the memory. As we have already seen, hitting clear (C) does not clear the memory. To clear the memory you need to hit memory recall two times in a row. The first time you hit it you recall the memory:

and the second time you hit it you clear the memory:

Note that the 108 is still in the display but that the small M has gone. Simply hit clear (C) to return the display to zero. If your calculator has a memory clear key on it (usually “MC”) then simply hit this at any time to clear the memory.

The memory button is a very useful tool and it is well worth your while mastering it, so here is one more worked example for you to work through and then you can try a few yourself.

Calculation: (12.5 x 0.052) - (8.6 x 0.052)	
Action	**Display Shows**
Hit clear (C)	0.
Do the second calculation first.	
Enter 8.6	8.6
Hit multiply key (x)	8.6
Enter 0.052	0.052
Hit equals key (=)	0.4472
Hit memory plus key (M+)	M 0.4472
The calculator has stored the answer to this calculation in the memory. You now need to do the first calculation.	
Hit clear (C)	M 0.
Enter 12.5	M 12.5
Hit multiply key (x)	M 12.5
Enter 0.052	M 0.052
Hit equals key	M 0.65
You now have the answer to the first calculation in the display and still part of the current calculation and the answer to the second calculation stored in the memory ready for you to use. You will now subtract the answer in the memory from the one in the display to get the final answer.	
Hit minus key (-)	M 0.65
Hit memory recall key (MR)	M 0.4472
The number in the memory has been entered into the calculation – in this case it will be subtracted from the previous number in the display – 0.65.	
Hit equals key (=)	M 0.2028
This is the final answer. Remember to clear the memory before starting a new calculation – (MR) (MR) (C).	

Try the following calculations using the memory buttons on your calculator – there are worked examples on the next few pages.

a) 6136 ÷ (11.8 x 0.052)

b) 325 ÷ (12,500 x 0.052)

c) (670 + 12,360) ÷ (4 x 12.5)

ANSWERS – DON'T LOOK UNTIL YOU'VE TRIED THEM

Calculation a)	6136 ÷ (11.8 x 0.052)
Action	Display Shows
Hit clear (C)	0.
Enter 11.8	11.8
Hit multiply key (x)	11.8
Enter 0.052	0.052
Hit equals key (=)	0.6136
Hit memory plus key (M+)	M 0.6136
Hit clear (C)	M 0.
Enter 6136	M 6136.
Hit divide key (÷)	M 6136.
Hit memory recall key (MR)	M 0.6136
Hit equals key (=)	M 10,000.
Don't forget to clear the memory before you start the next calculation.	

Calculation b)	325 ÷ (12,500 x 0.052)
Action	**Display Shows**
Hit clear (C)	0.
Enter 12500	12,500.
Hit multiply key (x)	12,500.
Enter 0.052	0.052
Hit equals key (=)	650.
Hit memory plus key (M+)	M 650.
Hit clear (C)	M 0.
Enter 325	M 325.
Hit divide key (÷)	M 325.
Hit memory recall key (MR)	M 650.
Hit equals key (=)	M 0.5.
Don't forget to clear the memory before you start the next calculation.	

Calculation c)	(670 + 12,360) ÷ (4 x 12.5)
Action	**Display Shows**
Hit clear (C)	0.
Enter 4	4.
Hit multiply key (x)	4.
Enter 12.5	12.5
Hit equals key (=)	50.
Hit memory plus key (M+)	M 50.
Hit clear (C)	M 0.
Enter 670	M 670.
Hit plus key (+)	M 670.
Enter 12360	M 12,360.
Hit equals key (=)	M 13,030.
Hit divide key (÷)	M 13,030.
Hit memory recall key (MR)	M 50.
Hit equals key (=)	M 260.6
Don't forget to clear the memory before you start the next calculation.	

The memory button is a very useful function on your calculator. It will be well worth your while learning how to use it.

FRACTIONS AND DECIMALS

Calculators work in decimals – that is to say in factors of ten. The number 1 is one tenth of ten, 100 is ten tens and so on. An important part of the decimal system is the decimal place (or point as we will call it). The decimal point is used to let you know where whole numbers end and the parts of a number that are smaller than one begin.

All numbers to the left of the decimal point are whole numbers - one or more. All numbers to the right of the decimal point are smaller than one. The table below shows the relationship between some of these numbers.

billions	hundreds of millions	tens of millions	millions	hundreds of thousands	tens of thousands	thousands	hundreds	tens	ones	decimal point	tenths	hundredths	thousandths	ten thousandths	hundred thousandths
1,	2	3	4,	5	6	7,	8	9	1	.	2	3	4	5	6

Note the comma every three numbers to the left of the decimal point. This is used as a marker so you can quickly see what a number is. Sometimes in a calculator the comma marker may be at the top of the number. The number shown above (1,234,567,891.23456) is:

One billion, two hundred and thirty four million, five hundred and sixty seven thousand, eight hundred and ninety one point two, three, four, five, six!!

Calculators work in decimals – you can add, subtract, multiply and divide decimals in a calculator without having to do anything else to a number beforehand.

You have already seen this in action earlier in this chapter when we were looking at how to use your calculator. Have a look back to see if you are unsure.

In the drilling industry one of our key numbers is not normally given as a decimal but is expressed as a fraction - when we are talking about diameters. Hole diameter, the outside diameter (OD) of tubulars and sometimes the inside diameter (ID) of tubulars are commonly measured in inches and fractions of an inch. Fractions are the bits that are less than one.

We have 3 $^1/_2$ inch drill pipe, 6 $^1/_4$ inch drill collars and 13 $^3/_8$ inch casing.

Before these numbers can be used in a calculator they need to be converted to decimals. This is a fairly straightforward process.

Spoken, 3 $^1/_2$ inches could be said as three and a half inches, which is three inches plus one half of an inch. So to convert the whole thing to a fraction we first need to convert the fraction of an inch to a decimal and then add it to the whole inches.

When you look at the fraction (1/2 in this case) you can see that it is made up of the number one (1) followed by a forward slash (/) followed by the number two (2). In calculations the forward slash is commonly used to tell you that you must divide the first number (or upper number) by the second number (or lower number).

So to covert 3$^1/_2$ inches to decimal you do the following:

$1 \div 2 = 0.5$

$3 + 0.5 = 3.5''$ the commas (") are shorthand for inches

Convert these other diameters from fractions into decimals:

a) 6 $^1/_4$"

b) 13 $^3/_8$"

c) 9 $^5/_8$"

d) 8 $^3/_4$"

e) 2 $^9/_{16}$"

ANSWERS

a) $^{1}/_{4}$"

= 1 ÷ 4 = 0.25

6 $^{1}/_{4}$ = 6 + 0.25 = 6.25"

b) $^{3}/_{8}$"

= 3 ÷ 8 = 0.375

13 $^{3}/_{8}$ = 13 + 0.375 = 13.375"

c) $^{5}/_{8}$"

= 5 ÷ 8 = 0.625

9 $^{5}/_{8}$ = 9 + 0.625 = 9.625"

d) $^{3}/_{4}$"

= 3 ÷ 4 = 0.75

8 $^{3}/_{4}$ = 8 + 0.75 = 8.75"

e) $^{9}/_{16}$"

= 9 ÷ 16 = 0.5625

2 $^{9}/_{16}$ = 2 + 0.5625 = 2.5625"

SQUARING NUMBERS

The square of a number is simply the number multiplied by itself. It is normally shown with a little ^{2} at the top right-hand corner of the number you have to square.

For instance, two squared would be shown as 2^2 and means 2 x 2.

To square a number in your calculator you can either hit

2 x 2 = or 2 x = either way you will get 4 as the answer.

Try both methods to see.

Now square the following in your calculator:

a) 9^2 b) 37^2 c) 8 $1/2^2$ d) 9 $5/8^2$

ANSWERS – DON'T LOOK UNTIL YOU'VE TRIED THEM

a) $9^2 = 81$ (key strokes 9 x =)

b) $37^2 = 1{,}369$ (key strokes 37 x =)

c) $8\ ^1/_2\ ^2$ – first convert this to a decimal

1/2 = 1 ÷ 2 = 0.5

8 + 0.5 = 8.5

$8.5^2 = 72.25$ (key strokes 8.5 x =)

d) $9\ ^5/_8\ ^2$ – first convert this to a decimal

5/8 = 5 ÷ 8 = 0.625

9 + 0.625 = 9.625

$9.625^2 = 92.640625$ (key strokes 9.625 x =)

PERCENTAGES

The term percent means “of a hundred” and is a decimal fraction that is used in various ways to describe how much of the whole you have. The symbol for percent is %, which you will recognise as a fraction - OK, it’s a very small fraction (0 ÷ 0 = 0) but a fraction nonetheless!

The term 25% could also be written as 25/100. This is the same thing as 1/4 – both calculations work out to 0.25 – try them.

Percentages can be used in various ways during calculations to look at the relationship of one number compared to the whole, and in drilling calculations are always to do with numbers of real things.

For instance, if there were 100 pairs of gloves in the store and 25 pairs were issued to the crew then 25 out of a hundred, or 25%, have been issued. It therefore stands to reason that 75 out of a hundred, or 75%, remain.

Percentages can be used with any amounts, not just 100, in five main ways.

1) You can work out what a given percentage of something is.

2) You can work out what percentage of something any given amount is.

3) You can work out how much something is if you know how much a certain percentage of it is.

4) You can add a given percentage to something.

5) You can subtract a given percentage from something.

Over the next few pages we will look at each of the five different calculations in turn.

This topic is best done when fresh - take a break before you start or, call it quits today and, tackle it first thing when you next study.

1) Working out what a given percentage of something is.

The liquid mud seal on the mud gas separator is good for 24 psi. An alarm will go off when the pressure reaches 75% of this value. At what pressure will the alarm go off?

There are two ways to tackle this one – longhand or using the % key on your calculator.

To do it longhand, first convert the percentage to a decimal and then multiply this by the number you are trying to find a percentage of.

In this case:

$$75 \div 100 = 0.75$$

$$0.75 \times 24 = 18 \text{ psi}$$

To use the percent key on your calculator start with the number you have then multiply it by the percentage you are trying to find out, then hit the percent key. The answer will be shown in the display when you hit the % key - there is no need to hit the equals key.

24 x 75 % (this is the order you enter the calculation)

the display will show - 18.

Try the following:

a) What is 47% of 7,700?

b) The company pays 2.5% of salary into a pension scheme. Roustabouts get paid $3,500 per month – how much gets paid into their pension each month?

c) The BOP stack is rated for 15,000 psi. It is to be tested to 70% of this value. How much pressure will be applied at the test?

d) The rig is about to start a 90 day contract. The contract allows 2.5% downtime for rig maintenance. How many hours maintenance downtime is allowed in the contract?

ANSWERS

a) 47% = 47 ÷ 100 = 0.47

0.47 x 7,700 = 3,619

OR (calculator key strokes)

7700 x 47 % *gives* 3,619 (remember you do not need to hit the = key)

b) 2.5% = 2.5 ÷ 100 = 0.025 0.025 x 3,500 = $87.50 per month

OR

3500 x 2.5 % *gives* $87.50 per month

c) 70% = 70 ÷ 100 = 0.75 0.75 x 15,000 = 10,500 psi

OR

15000 x 70 % *gives* 10,500 psi

d) First work out how many hours there are in 90 days:

90 days x 24 hours per day = 2,160 hours in 90 days

2.5% = 2.5 ÷ 100 = 0.025 0.025 x 2,160 = 54 hours

OR

2160 x 2.5 % *gives* 54 hours

2) Working out what percentage something is.

We have just run 36 stands of drill pipe into the hole out of a total of 180 stands. What percentage has been run?

This can be done longhand or using the % key on your calculator.

Longhand you must divide the number you are trying to work out the percentage of by the total number, and then multiply the answer by 100.

In this case:

$$36 \div 180 = 0.2$$

$$0.2 \times 100 = 20 \text{ or } 20\%$$

Using the % key on your calculator enter the following key strokes:

36 ÷ 180 % gives 20% - try it.

Note: the percent symbol will not show in your calculator display.

In summary, to work out what percentage something is you must divide the number you have by the total number and then either multiply by 100 or hit the % key on your calculator.

Try the following:

a) What percentage of 2,345 is 469?

b) John is 3 $^{1}/_{2}$ days into a 28 day hitch. What percentage of his hitch has he completed?

c) The well depth is 15,625 feet with the casing run to 12,500 feet. What percentage of the hole is cased?

d) The well depth is 20,000 feet with casing run to 15,800 feet. What percentage of the hole is open?

ANSWERS

a) 469 ÷ 2,345 = 0.2 0.2 x 100 = 20%

OR (calculator key strokes)

469 ÷ 2345 % gives 20%

b) 3.5 ÷ 28 = 0.125 0.125 x 100 = 12.5%

OR

3.5 ÷ 28 % gives 12.5%

c) 12,500 ÷ 15,625 = 0.8 0.8 x 100 = 80%

OR

12500 ÷ 15625 % gives 80%

d) There are two ways to work this one out. You can work out what percentage is cased – the remainder will be open hole.

15,800 ÷ 20,000 = 0.79 0.79 x 100 = 79%

OR 15800 ÷ 20000 % gives 79%

100% - 79% gives 21% open hole

Alternatively, you could find out how much open hole you have in feet then work that out as a percentage.

20,000 – 15,800 = 4,200 feet of open hole.

4,200 ÷ 20,000 = 0.21 0.21 x 100 = 21%

OR 4200 ÷ 20000 % gives 21%

The answer works out the same no matter which way you go.

3) Working out how big something is if you know what a percentage of it is.

We are currently pumping at 80 strokes per minute (spm). This is 40% of the pump capacity. What are the maximum spm we can get?

Again, this can be done longhand or using the % key on your calculator.

Longhand you must divide the number you know by the percentage and then multiply the answer by 100. For this example that is:

80 ÷ 40 = 2 2 x 100 = 200 spm

Or using the % key on your calculator the key strokes are:

80 ÷ 40 % gives 200 spm *(remember you do not need to hit equals to get the final answer)*

In summary, to work out how big something is, if you know what percentage of the whole a given number is, you must divide the number you know by the percentage then either multiply the answer by 100 or hit the % key.

Try the following:

a) We are 75% of the way in the hole having run 132 stands. How many stands will we have to run to reach bottom?

b) There are 380 barrels (bbls) of mud in the mud pit, which is currently 80% full. How much mud will the pit hold when it is full?

c) The top drive is rotating at 156 revolutions per minute (rpm) and is operating at 65% capacity. How fast could the top drive turn?

d) We are currently applying 4,368 pounds per square inch (psi) of pressure to the shoe. This is 56% of fracture pressure. What is fracture pressure?

ANSWERS

a) 132 ÷ 75 = 1.76 1.76 x 100 = 176 stands

OR (calculator key strokes)

132 ÷ 75 % gives 176 stands

b) 380 ÷ 80 = 4.75 4.75 x 100 = 475 bbls

OR 380 ÷ 80 % gives 475 bbls

c) 156 ÷ 65 = 2.4 2.4 x 100 = 240 rpm

OR 156 ÷ 65 % gives 240 rpm

d) 4,368 ÷ 68 = 78 78 x 100 = 7,800 psi

OR 4368 ÷ 68 % gives 7,800 psi

The two percentage calculations we have just looked at are very similar as you will have noticed. In both cases you divide one number by another and then either multiply by 100 or hit the % key on the calculator.

In both cases you start with the number you know (i.e. stands of pipe, spm etc.) You must then divide that by the other number you know – which will either be the total amount you have or the percentage of the total amount. Finally, multiply by 100.

4 & 5) To add or subtract a given percentage from the total. These are pretty much the same so we'll deal with them together.

We have worked out that we need 160 gallons (gals) of usable fluid to operate our Blowout Preventers (BOP). Policy requires us to have an extra 15% of operating fluid available. How much fluid will we need in total?

To work this out longhand you must first work out how much 15% of the total is (which you have already covered) and then you add this to the total.

15% = 0.15 160 x 0.15 = 24

160 + 24 = 184 *gals*

Using the % key on your calculator the key sequence is:

160 + 15 % *gives* 184 *gals*

To subtract a percentage from the total simply replace the plus with a minus in either of the above methods.

Try the following:

a) A cement job requires 850 bbls of cement. The company man wants an extra 22% to be ready. How much cement is needed?

b) A new bit design means that we can get 17% more footage per bit in a given hole section. We were getting 2,300 feet per bit before. How many feet will the new bit be able to drill?

c) A new mud additive has improved solids loss to the formation and reduced the cost per barrel of mud by 13%. If our previous cost was $75 per barrel, what will the new cost be?

d) Now for the bad news! Due to the financial climate toolpushers are going to receive an 8% cut in their salary (maybe not that bad news really!) Toolpushers currently earns $8,500 per month. What will their salary be after the pay cut takes effect?

ANSWERS

a) 22% = 0.22 850 x 0.22 = 187

850 + 187 = 1037 bbls

OR 850 + 22 % gives 1037 bbls

b) 17% = 0.17 2,300 x 0.17 = 391

2,300 + 391 = 2,691 ft

OR 2300 + 17 % gives 2,691 ft

c) 13% = 0.13 75 x 0.13 = 9.75

75 - 9.75 = 65.25 $/bbl This one is a subtraction!

OR 75 - 13 % gives 65.25 $/bbl

d) 8% = 0.08 8,500 x 0.08 = 680

8,500 - 680 = 7,820 $/month

OR 8500 - 8 % gives 7,820 $/month

Now here is a bunch of mixed up percentage calculations to try. Each time you will have to figure out which one of the five percentage calculations you have to use first and then do the calculation. They are in no particular order but do go back and look at the last few pages to help you figure things out if you need to.

a) The rig day rate is $182,250 which gives an operating profit of 35% above cost. How much does the rig cost to operate per day?

b) The trip tank holds 42 bbls of mud. On a trip out the level will fall as mud from the trip tank replaces the pipe that is being removed from the hole.

Standing Instructions state that the trip tank level must not fall below 13% of capacity. What is the minimum volume of mud that must be kept in the trip tank?

c) The mud weight has been increased from 16 ppg to 16.8 ppg. What has been the percentage increase in the mud weight?

d) The string measured length is 14,780 ft. The BHA and Hevi Weight combined make up 11% of the total string length - the remainder is drill pipe.

What is the length of the drill pipe?

ANSWERS

a) This is an example of the third type of percentage calculation where you know a given percentage of the whole and have been asked to work out what 100% is.

In this case you have been told that $182,250 is cost plus 35% - or put another way $182,250 is 135%.

To work out cost (or 100%) do the following in your calculator:

182250 ÷ 135 % to get a final answer of: $135,000/day

b) This is an example of the first type of percentage calculation asking you to work out a given percentage of something.

In this one, what is 13% of 42 bbls?

42 x 13 % gives 5.46 bbls *(remember you do not need to hit the equals key)*

c) This is an example of the second type of percentage calculation asking you to work out what something is as a percentage.

Here you have to work out what percentage of the original mud weight the increase has been.

First work out the increase: 16.8 - 16 = 0.8

Then work out what percentage of the original mud weight this is:

0.8 ÷ 16 % gives 5% mud weight increase

d) This is another example of the first type of percentage calculation.

This one can be tackled two ways.

Firstly work out what 11% of the total is then subtract that from the total to get the length of the drill pipe.

14780 x 11 % gives 1,625.8

14780 - 1625.8 = 13,154.2 ft of drill pipe

This is a great chance for you to use the memory function on your calculator as you subtract the answer to the first calculation in the second calculation.

Try it - the calculator key strokes are as follows:

14780 x 11 % M+ C 14780 - MR = and you get 13,154.2

Do not forget to clear the memory now.

The other way to tackle it is to work out what percentage of drill pipe you have and then do the percentage calculation.

100 - 11 = 89% drill pipe - 14780 x 89 % gives 13,154.2 ft of drill pipe

How about doing this one using the memory?

Key strokes are:

100 - 11 = M+ C 14780 x MR % and you get 13,145.2 as an answer

The memory function on your calculator can be very useful once you have figured out how to use it properly. Look for opportunities to use it particularly where you subtract or divide the answer from one calculation in a second one.

ROUNDING ANSWERS

So far most of the calculations we have looked at have had answers that make sense. Try this one in your calculator:

7,830 ÷ 11,750 ÷ 0.052

If your calculator display shows ten digits then the answer you have will be 12.81505726, but how much of this number do you actually need?

If I told you that this answer was a mud weight in ppg you may start to think that one or two decimal places would be accurate enough. Try weighing the mud up by 0.005 ppg - five thousandths of a pound per gallon!!

In drilling calculations you need to be able to round your final answer so it gives a sensible number. When you round an answer you may shorten it or you may leave it the same length but you will get rid of some of the numbers as they give a degree of accuracy that is not needed for the situation you are working in.

For mud weights in ppg like the one above we generally round the answer to two decimal places, but what does this mean?

To start with, two decimal places means the final answer will have two numbers after the decimal point. Easy enough to understand so far but what is meant by rounding the answer?

In calculations when you round an answer you must first look at the number immediately to the right of where you are rounding to. In the above example you have been asked to round to two decimal places so the number immediately to the right is a 5 (12.81**5**).

The rule is that if this number is five or greater then you increase the number you have been asked to round to, up, by one. If this number is less than five then you leave the number you have been asked to round to as it is.

In the above example the number to the right of the second decimal place is 5 so you must round the number up by one. This means that 12.81 becomes 12.82 ppg.

In the field you would only really be able to weigh a mud weight to an accuracy of one decimal place. What would the mud weight be to one decimal place?

The original number to the right of the first decimal place is a 1 which means the first decimal place is left as it is.

12.81 is rounded to 12.8 ppg

The rounding rule states that if the number to the right of the one you are rounding to is less than five you need do nothing, and if the number to the right of the one you are rounding to is five or greater you round up.

Work out the following mud weights rounded to two decimal places:

a) 0.445 ÷ 0.052

b) 0.8 ÷ 0.052

c) 6,500 ÷ 0.052 ÷ 8,750

d) 500 ÷ 0.052 ÷ 12,500

ANSWERS

a) 0.445 ÷ 0.052 = 8.557692307

Rounding to two decimal places you look at the third number to the right of the decimal point which is a 7. This is greater than five so you must increase the second decimal by one from 5 to 6 giving a final answer of:

8.56 ppg *(this is the weight of seawater in many parts of the world)*

b) 0.8 ÷ 0.052 = 15.38461538

The third decimal is 4, therefore we leave the second one as it is to get:

15.38 ppg

c) 6,500 ÷ 0.052 ÷ 8,750 = 14.28571426

The third decimal is 5, therefore we raise the second by one to get:

14.29 ppg

d) 500 ÷ 0.052 ÷ 12,500 = 0.769230769

The third decimal is 9, so we raise the second by one to get:

0.77 ppg *(this is a mud weight increase which is why it is so small)*

The rounding rule applies to all calculations, not just mud weights, and remains the same - if the number to the right of the one you are rounding to is less than five you need do nothing, and if the number to the right of the one you are rounding to is five or greater you round up.

Using the following calculation work out bottom hole pressure to the nearest whole psi:

12.47 x 0.052 x 6,500

This comes to 4,214.86 psi. We want the answer in whole psi. The number to the right of the one we are rounding to is the 8 to the right of the decimal point. This is greater than five so we must raise the 4 by one to 5, giving a final answer of:

4,215 psi

Try this one:

9,200 ÷ 0.052 ÷ 15

What is the well depth to the nearest ten feet?

9,200 ÷ 0.052 ÷ 15 = 11,794.87178

The number to the right of the tens is 4, which is less than five, giving a final answer of:

11,790 ft

Round the following:

a) 0.0119 x 780 in bbls to two decimal places

b) 185,500 x 63 in dollars to the nearest hundred thousand

c) 4.276^2 ÷ 1029.4 in bbl/ft to five decimal places

d) 5,700 ÷ 0.052 ÷ 10,000 in ppg to one decimal place

ANSWERS

a) $0.0119 \times 780 = 9.282$

You are going to two decimal places and the third is 2 so you get:

9.28 bbl

b) $185{,}500 \times 63 = 11{,}686{,}500$

↑

You are going to the nearest hundred thousand and the number to the right of this is 8 (shown by the arrow), so you need to round the hundred thousands up by one to get:

$11,700,000

c) $4.276^2 \div 1029.4 = 0.017761973$

↑

You need to look at the sixth decimal place which is 1 (shown by the arrow), so the fifth decimal place stays the same giving:

0.01776 bbl/ft *(This is the internal capacity of 5 inch drill pipe)*

d) $5{,}700 \div 0.052 \div 10{,}000 = 10.96153846$

Taking this answer to one decimal place you look at the second which is 6, so the first must be rounded up by one. The first decimal is 9 which becomes 10. In this instance you will now have to increase the whole from zero to 1 giving a final answer of:

11.0 ppg

SYMBOLS USED IN CALCULATIONS

It is almost time to look at formulas which for many is the daunting part of calculations, particularly when you see something like that shown below:

$$\frac{0.5928 \times (0.0075 + 0.0178)}{0.0729 - (0.0075 + 0.0178)} \times 93$$

The first thing to remember is that most of the time you will only be doing one of four basic calculations - adding, subtracting, multiplying or dividing two numbers. You may have to do this several times in succession to get to the final answer but these are the main calculations you will be doing. Occasionally you may also have to square a number, but that is it.

Taken individually they are not in the least bit tricky. Taken as a complete calculation they should be no trickier. The key is learning the order in which you tackle a calculation and then applying some planning and discipline to tackling the calculation.

Before we tackle the order let's ensure we understand what the symbols mean.

Symbol	What you have to do
+	Add the two numbers either side of the symbol together
-	Subtract the number on the right of the symbol from the number on the left
x	Multiply the numbers either side of the symbol by each other
÷	Divide the number on the left of the symbol by the number on the right
/	Divide what is on the left of the symbol by what is on the right
$\frac{10}{2}$	Divide what is above the line by what is below the line
n^2	Square the number (here the *n* is taking the place of the number)
( )	Brackets are used to close off or isolate part of a calculation

You will have noticed there are three different ways of showing divide, but they all mean the same thing.

FIGURING OUT THE ORDER OF A CALCULATION

OK, now you know what the symbols mean (you probably already did) you now need to use them in the correct order through a calculation.

The order in which a calculation should be done is:

1) Do anything inside brackets first

2) Square anything that needs squaring

3) Do any multiplications and divisions

4) Add and subtract

If you have a complex formula with calculations above and below the line you must complete those calculations first.

A well written formula tells you the order of the calculation once you know how to read it. Let's have another look at the calculation from the previous page and see what it is telling us:

$$\frac{0.5928 \times (0.0075 + 0.0178)}{0.0729 - (0.0075 + 0.0178)} \times 93$$

The first thing to note is that there are calculations above and below the line. This is telling you that you must divide the answer to the calculation above the line by the answer to the calculation below the line.

Both above and below the line there are calculations inside brackets so they must be done before any other calculations above and below the line are tackled.

Finally, the answer to the division shown by the line has to be multiplied by 93.

You should write all calculations down and tackle them in stages. So how do you tackle this calculation?

Start by writing the calculation down exactly as it is shown:

$$\frac{0.5928 \times (0.0075 + 0.0178)}{0.0729 - (0.0075 + 0.0178)} \times 93$$

First you must do the calculations inside the brackets - both above and below the line. Do this and write the answers down, making sure you put them in the correct place in the calculation:

$$\frac{0.5928 \times 0.0253}{0.0729 - 0.0253} \times 93$$

Note how the answers to the two calculations inside the brackets are in the same place as the brackets originally were. Also note that all other numbers are still where they were before.

Next you must finish off the calculations above and below the line, again writing the complete answers down in the correct place:

$$\frac{0.01499784}{0.0476} \times 93$$

Now it is time to do the division shown by the line, leaving you with:

$$0.315080672 \times 93$$

The calculation is finished off by doing the last multiplication to get:

$$29.30250249$$

This calculation works out a pressure drop in psi and could therefore be rounded to the nearest whole psi giving a final answer of:

29 psi

Note that the answers to the individual stages of the calculation are carried through in their entirety. It is very important for the accuracy of the final answer not to round until the very end.

Well, that was pretty straightforward don't you think? Here are a couple more then you're on your own for a few.

$$\left(\frac{30}{80}\right)^2 \times 2{,}500$$

OK, what have we here? There is a division inside the brackets, a number to be squared and a multiplication.

In stages this will look as follows:

$$\left(\frac{30}{80}\right)^2 \times 2{,}500$$

$= (0.375)^2 \times 2{,}500$ *the division has been done*

$= 0.140625 \times 2{,}500$ *the number has been squared*

$= 351.5625$ *the multiplication has been done*

This is a pump pressure in psi so could be rounded to the nearest psi to get a final answer of:

$= 352$ psi

In this example you will notice an equals sign has been used at each stage of the calculation. The equals sign tells you that this line is equal to the line before it even though it looks different. The difference is that you have completed part of the calculation.

Using the equals sign between stages of a complicated calculation will also allow you to keep track of where you are in a calculation. This can be a big help, especially when things start to get complicated!

Now if you've ever tried to read one psi on a pump gauge you'll know it is nigh on impossible. What would the answer to this calculation be to the nearest ten psi?

The answer is at the top of the opposite page but work it out before you look.

To the nearest ten psi the new pump pressure will be 350 psi.

How about this example? The answer is a mud weight in ppg rounded to one decimal place.

$$\frac{320}{12{,}300 \times 0.052} + 11.4$$

There is a calculation below the line to be done before the division the line is indicating, and finally you have to add 11.4 before rounding.

$$\frac{320}{12{,}300 \times 0.052} + 11.4$$

$= \frac{320}{639.6} + 11.4$ *the calculation below the line has been done*

$= 0.500312695 + 11.4$ *the division shown by the line has been done*

$= 11.9003121269$ which is rounded to 11.9ppg

Figure out the following:

a) $\left(\frac{14.2}{12.6} - 1\right) \times 30$ in bbls rounded to one decimal place

b) $11.4 \times 0.052 - \left(\frac{780 - 620}{400}\right)$ in psi/ft to three decimal places

c) $\left(\frac{35 - 23.4}{0.07 - (0.01776 + 0.0077)}\right) + 730$ in feet to the nearest foot

d) $\left\{\left(\frac{1000}{1200}\right) - \left(\frac{1000}{3000}\right)\right\} \times 10$ in gallons to one decimal place

ANSWERS

a) $\left(\frac{14.2}{12.6} - 1\right) \times 30$

= $(1.126984126 - 1) \times 30$

= 0.126984126×30

= 3.80952378 which rounds to 3.8 bbls

b) $11.4 \times 0.052 - \left(\frac{780 - 620}{400}\right)$

Although there are no brackets round the left-hand side of the calculation, the order tells us we do multiplications before subtractions so we can multiply 11.4 by 0.052.

The calculation inside the brackets can also be done as one, namely subtracting 620 from 780 then dividing by 400. This means at the end of the first stage we will have:

= 0.5928 - 0.4

= 0.1928 which rounds to 0.193 psi/ft

You will have noticed, however, that the memory button is screaming out to be used in this one!

Do the second calculation first; store the answer in the memory; do the first calculation and then recall the memory for the subtraction.

As key strokes you hit:

780 - 620 ÷ 400 = M+ C 11.4 × 0.052 = - MR = to give 0.1928

Did I mention how useful the memory function can be?

c) $$\left(\frac{35 - 23.4}{0.07 - (0.01776 + 0.0077)}\right) + 730$$

$$= \left(\frac{11.6}{0.07 - (0.02546)}\right) + 730$$

$$= \left(\frac{11.6}{0.04454}\right) + 730$$

$= 260.4400538 + 730$

$= 990.4400538$ which rounds to 990 ft

There is a bit of a shortcut with the bottom line above:

$0.07 - (0.01776 + 0.0077)$ is the same thing as $0.07 - 0.01776 - 0.0077$. If you spotted it you could eliminate a stage but don't worry if you didn't as it's better to get the right answer than to find shortcuts.

d) $$\left\{\left(\frac{1000}{1200}\right) - \left(\frac{1000}{3000}\right)\right\} \times 10$$

When you are faced with brackets inside brackets you must start with the inside set of brackets and work out the way.

$= (0.833333333 - 0.333333333) \times 10$

$= 0.5 \times 10$

$= 5$ gals

Once again that memory function is calling out!

1000 ÷ 3000 = M+ C 1000 ÷ 1200 = - MR = x 10 = to get 5

FORMULAS

The time has come to look at formulas! A formula is nothing to be worried about. It is simply a way of telling you how to use information you know to work out something you want to know. It is a set of instructions for a calculation.

For instance, a roughneck's daily salary is $525/day. If he works a 14 day hitch how much will his salary be?

Simple: 525 x 14 = $7,350

This could be written as a formula as follows:

Roughneck's Salary = 525 x Days Worked

In this formula we have one constant and one variable. A constant in a formula is a number that does not change - in this case the daily salary of $525. What can change in this formula is the number of days work - it is the variable and affects the final answer. If the roughneck works more days the salary will change.

Now, the same calculation could be used to work out the salary of anyone on the rig but we could not use the same formula as each person's daily salary will be different. The formula would have to be rewritten as:

Salary ($) = Daily Salary ($/day) x Days Worked

This time there are no constants, only variables, but it will allow you to work out anyone's salary if you know their daily salary and how long they work.

Note the bit in the smaller brackets in the formula. This is telling you what units you are working with. You will get an answer in dollars if you input dollars per day and the number of days.

It is important to pay attention to the unit when using a formula. If you put the wrong information in you will get the wrong answer.

Now, we all know that salary does not mean take-home pay - somewhere along the line there is a tax man (or woman) who wants a cut!

Let's say that tax of 23% is paid at source by the employer and the amount paid at the end of the hitch is take-home pay. The formula would now be:

Take-Home Salary ($) = (Daily Salary ($/day) x Days Worked) - 23%

The formula now has two variables and a constant.

A roughneck's take-home salary for a fourteen day hitch will be:

Take-Home Salary = (525 x 14) - 23%

= 7,350 - 23% (key strokes 7350 - 23 %)

= $5,659.50

We also all know that tax rates change - it seems like they always go up but sometimes they do come down. This means the formula could read:

Take-Home Salary ($) = (Daily Salary ($/day) x Days Worked) - Tax Rate (%)

We have just developed a formula that will work in any situation and will allow us to work out take-home pay for anyone on the rig, for any length of hitch worked, using the current tax rate.

All formulas you will be asked to use will have been worked out in pretty much the same way. All formulas are a set of instructions telling you how to do a calculation.

Using the formula above work out to the nearest dollar how much a mechanic ($730/day), roustabout ($375/day) and driller ($740/day) will take home for a 21 day hitch if the current tax rate is 19.75%.

ANSWERS

Take-Home Salary ($) = (Daily Salary ($/day) x Days Worked) - Tax Rate (%)

<u>Mechanic</u>

Take-Home Salary = (730 x 21) - 19.75%

= 15,330 - 19.75%

= 12,302.325

= $12,302

<u>Roustabout</u>

Take-Home Salary = (375 x 21) - 19.75%

= 7,875 - 19.75%

= 6,319.6875

= $6,320

<u>Driller</u>

Take-Home Salary = (740 x 21) - 19.75%

= 15,540 - 19.75%

= 12,470.85

= $12,471

Note how the three calculations have been clearly identified and that at the start all the numbers have been put down exactly as the formula requires them. Each calculation has been done in stages and the final answer has the unit included ($ in this case).

Also note that a line has been drawn across the page after each calculation, keeping them separate. Use this kind of discipline for all calculations you do.

We are now going to use some drilling formulas. This chapter is not about understanding what the formulas mean it is about understanding how to use them. We will look at what they mean in later chapters.

Questions involving formulas are problem-solving exercises. You will be given some information and a formula to work out an answer. Your task is to get the information into the correct place in the formula and then to carry out the calculation in the correct order.

Using the formulas and the well data given answer the questions below.

<u>Formulas</u>

Hydrostatic Pressure (psi) = Current Mud Weight (ppg) x 0.052 x Well TVD (ft)

Max Mud Weight (ppg) = (LOT Pressure (psi) ÷ 0.052 ÷ Shoe TVD (ft)) + Test Mud Weight (ppg)

MAASP (psi) = (Max Mud Weight (ppg) - Current Mud Weight (ppg)) x 0.052 x Shoe TVD (ft)

$$\text{Kill Mud Weight (ppg)} = \frac{\text{SIDPP (psi)}}{\text{Well TVD (ft)} \times 0.052} + \text{Current Mud Weight (ppg)}$$

<u>Well Data</u>

Test Mud Weight = 10.4 ppg

Current Mud Weight = 11.8 ppg

Well TVD = 11,564 ft

Shoe TVD = 9,875 ft

SIDPP = 640 psi

LOT Pressure = 1,650 psi

a) What is Kill Mud Weight?

b) What is Current Hydrostatic pressure?

c) What is Current MAASP?

Mud weights should be rounded to one decimal place and pressures to the nearest whole psi.

ANSWERS

a) What is Kill Mud Weight?

$$\text{Kill Mud Weight (ppg)} = \frac{\text{SIDPP (psi)}}{\text{Well TVD (ft)} \times 0.052} + \text{Current Mud Weight (ppg)}$$

$$\text{Kill Mud Weight} = \frac{640}{11{,}564 \times 0.052} + 11.8$$

$$= \frac{640}{601.328} + 11.8$$

$$= 1.0643100991 + 11.8$$

$$= 12.86431099$$

$$= 12.9 \text{ ppg}$$

---

b) What is Current Hydrostatic pressure?

$$\text{Hydrostatic Pressure (psi)} = \text{Current Mud Weight (ppg)} \times 0.052 \times \text{Well TVD (ft)}$$

$$\text{Hydrostatic Pressure} = 11.8 \times 0.052 \times 11{,}564$$

$$= 7{,}095.6704$$

$$= 7{,}096 \text{ psi}$$

c) What is Current MAASP?

MAASP (psi) = (Max Mud Weight (ppg) - Current Mud Weight (ppg)) x 0.052 x Shoe TVD (ft)

Bummer! Max Mud Weight has not been given in the Well Data!

You have, however, been given a formula to work out Max Mud Weight and enough information to do so.

You are going to have to work out Max Mud Weight to be able to answer the question.

Max Mud Weight (ppg) = (LOT Pressure (psi) ÷ 0.052 ÷ Shoe TVD (ft)) + Test Mud Weight (ppg)

Max Mud Weight = (1,650 ÷ 0.052 ÷ 9,875) + 10.4

= 3.213242453 + 10.4

= 13.61324245

= 13.6 ppg

You now have all the information you need to work out MAASP.

MAASP (psi) = (Max Mud Weight (ppg) - Current Mud Weight (ppg)) x 0.052 x Shoe TVD (ft)

MAASP = (13.6 - 11.8) x 0.052 x 9,875

= 1.8 x 0.052 x 9,875

= 924.3

= 924 psi

As you work through the remaining three sections you will use more and more formulas, some more straightforward than others, but all easily manageable now you know how to work with them.

Remember, most of the time you will only be doing one of four things - adding, subtracting, multiplying or dividing.

MESSING WITH FORMULAS

Now you've got the hang of working with formulas it's time to look at how you can rearrange them to help work out something you need to know.

From the following information work out Hydrostatic Pressure (don't worry what the terms mean just now - just focus on the mechanics of the calculation).

Formula: BHCP = Hydrostatic Pressure + APL

Data: BHCP = 5,700 psi APL = 400 psi

So what have we got?

We have a formula for BHCP and we've been asked to work out Hydrostatic Pressure. We have been given the values of BHCP and APL.

If we put the information we know into the correct place in the formula we would get:

BHCP = Hydrostatic Pressure + APL

5,700 = Hydrostatic Pressure + 400

It is obvious from looking at the calculation that Hydrostatic Pressure is equal to 5,300:

5,700 = 5,300 + 400

The calculation could be rearranged to allow you to work out Hydrostatic Pressure:

5,700 - 400 = 5,300

This means the formula could also be rearranged to allow you to work out Hydrostatic Pressure:

BHCP - APL = Hydrostatic Pressure

Occasionally you may come across a question that asks you to work out something without a formula for it. You may have a different formula that contains the piece of information you are trying to work out. It will be up to you to rearrange the formula so you can work out what you are after.

But how do you do that? Previously we said that a formula was a set of instructions telling you how to do a calculation, and this still stands. All formulas have the unknown on one side of an equals sign and a calculation on the other side:

BHCP = Hydrostatic Pressure + APL

The equals sign is telling you that the value of one side of it is the same as the value on the other side of it:

5,700 = 5,300 + 400 or when worked out

5,700 = 5,700

We rearranged this to say that:

BHCP - APL = Hydrostatic Pressure or in numbers

5,700 - 400 = 5,300 which works out as

5,300 = 5,300

Although the numbers have changed the values on both sides are still equal, different numbers than at the start, but still equal to each other.

A formula is a statement that says mathematically:

This Number = This Number

As long as we make sure both sides are equal the maths will work out.

So, a formula is a statement that says:

This Number = This Number

and as long as we make sure both sides are equal the maths will work out.

How do we make sure that we keep both sides equal? What mathematical rules do we need to apply when rearranging a formula?

We rearranged the formula by taking a value from one side to the other:

BHCP = Hydrostatic Pressure + APL became

BHCP - APL = Hydrostatic Pressure

APL has changed sides of the equals sign. Can you see what happened to it when it changed sides?

On the original side we were adding it, when it changed sides we subtract it.

How about this calculation:

$10 = 2 \times 5$ which works out as $10 = 10$

The value on one side equals the value on the other

This can be rearranged to read:

$10 \div 5 = 2$ which works out as $2 = 2$

What happened to the 5 when it changed sides?

On the original side we were multiplying it, when it changed sides we must divide by it.

When a value crosses from one side of the equals sign to the other you must do the opposite calculation on it - an addition becomes a subtraction, a subtraction becomes an addition, a multiplication becomes a division and a division becomes a multiplication.

In summary:

If on the original side you	then when it changes side you must
add the number	subtract the number
subtract the number	add the number
multiply by the number	divide by the number
divide by the number	multiply by the number

Let's try a few:

Strokes = Volume ÷ Pump Output

How would you work out volume?

Strokes = Volume ÷ Pump Output

Pump Output has to swap sides and change from a division to a multiplication.

Strokes x Pump Output = Volume

This one's a bit trickier:

Time = Strokes ÷ Pump Output

How would you work out Pump Output? You will have to do this in a couple of stages. Firstly take the Pump Output across to the other side then move the Time over the other way:

Time = Strokes ÷ Pump Output

Time x Pump Output = Strokes

Pump Output = Strokes ÷ Time

It is trickier to move something you are ***dividing into*** - tackle it in stages.

What about this one then?

Hydrostatic Pressure = Mud Weight x 0.052 x TVD

How would you work out mud weight?

Do not try do this all at once - take it in stages moving one thing at a time.

Move TVD first - it multiplies on one side so it must divide on the other:

Hydrostatic Pressure = Mud Weight x 0.052 x TVD

Hydrostatic Pressure ÷ TVD = Mud Weight x 0.052

Now move the constant 0.052. Again, it changes from a multiply to a divide:

Hydrostatic Pressure ÷ TVD ÷ 0.052 = Mud Weight

Usually what we do now to tidy things up is flip the formula over so it reads better:

Mud Weight = Hydrostatic Pressure ÷ TVD ÷ 0.052

Let's try it with some numbers to see if it really works.

Data: Mud Weight = 10 TVD = 10,000

Hydrostatic Pressure = Mud Weight x 0.052 x TVD

Hydrostatic Pressure = 10 x 0.052 x 10,000

= 5,200

Mud Weight = Hydrostatic Pressure ÷ TVD ÷ 0.052

= 5,200 ÷ 10,000 ÷ 0.052

= 10

It works!

Here's a wee trick that can help with rearranging formulas if you're not sure what to do.

Put some really basic numbers into the formula then rearrange things until the number you are after is on its own.

Let's go back and look at one from the previous pages. We were given:

Time = Strokes ÷ Pump Output

and were asked to work out Pump Output. Let's make this a really simple calculation that we can see just by looking at it:

$$5 = 10 \div 2$$

where 5 stands for Time, 10 stands for Strokes and 2 stands for Pump Output

What calculation will give us 2 (Pump Output) as an answer?

$$2 = 10 \div 5$$

We said that 5 stands for Time, 10 stands for Strokes and 2 stands for Pump Output so the formula becomes:

Pump Output = Strokes ÷ Time

This trick works for some people, others prefer to use the rules. Both will work as long as you take your time and keep things clear. If go this way make sure each number you use is different.

Rearrange the Hydrostatic Pressure formula so you can work out TVD.

Hydrostatic Pressure = Mud Weight x 0.052 x TVD

ANSWERS

This can be tackled two ways - firstly using the mathematical rules and moving one thing at a time:

Hydrostatic Pressure = Mud Weight x 0.052 x TVD

Hydrostatic Pressure ÷ Mud Weight = 0.052 x TVD

Hydrostatic Pressure ÷ Mud Weight ÷ 0.052 = TVD

Tidy it up by flipping the formula over to get:

TVD = Hydrostatic Pressure ÷ Mud Weight ÷ 0.052

Secondly let's look at using some basic numbers in the formula first, and then rearranging them until they work:

Hydrostatic Pressure = Mud Weight x 0.052 x TVD

100 = 2 x 5 x 10

Where 100 stands for Hydrostatic Pressure, 2 stands for Mud Weight, 5 stands for 0.052 and 10 stands for TVD. We want to get 10 as the answer:

10 = 100 ÷ 2 ÷ 5 which tells us that:

TVD = Hydrostatic Pressure ÷ Mud Weight ÷ 0.052

Here's the table again showing you what you need to do to rearrange a formula.

If on the original side you	then when it changes side you must
add the number	subtract the number
subtract the number	add the number
multiply the number	divide by the number
divide by the number	multiply by the number

Rearrange the following formulas either using the rules above or by replacing the formula with some basic numbers.

a) ICP = SCR + SIDPP

How do you work out the SCR value?

b) P1 x V1 = P2 x V2

How do you work out P2?

c) $FCP = \frac{KMW}{OMW} \times SCR$

How do you work out KMW?

d) $\text{Mud Weight} = \frac{\text{Pressure}}{\text{TVD} \times 0.052}$

How do you work out TVD?

ANSWERS

a) How do you work out the SCR value?

ICP = SCR + SIDPP

ICP - SIDPP = SCR flipped to give

SCR = ICP - SIDPP

OR

ICP = SCR + SIDPP

10 = 6 + 4

6 = 10 - 4 which gives SCR = ICP - SIDPP

---

b) How do you work out P2?

$P1 \times V1 = P2 \times V2$

$\frac{P1 \times V1}{V2} = P2$ flipped to give

$P2 = \frac{P1 \times V1}{V2}$

OR

$P1 \times V1 = P2 \times V2$

$2 \times 10 = 5 \times 4$

$5 = \frac{2 \times 10}{4}$ which gives $P2 = \frac{P1 \times V1}{V2}$

c) How do you work out KMW?

$$FCP = \frac{KMW}{OMW} \times SCR$$

$$\frac{FCP}{SCR} = \frac{KMW}{OMW}$$

$$\frac{FCP}{SCR} \times OMW = KMW$$ flipped to give

$$KMW = \frac{FCP}{SCR} \times OMW$$

OR

$$FCP = \frac{KMW}{OMW} \times SCR$$

$$30 = \frac{6}{2} \times 10$$

$$6 = \frac{30}{10} \times 2$$ which gives

$$KMW = \frac{FCP}{SCR} \times OMW$$

d) How do you work out TVD?

$$\text{Mud Weight} = \frac{\text{Pressure}}{\text{TVD} \times 0.052}$$

To start with you need to treat the bottom line as being one number - use brackets to do this - and move it over to the other side where it becomes a multiplication.

$$\text{Mud Weight} \times (\text{TVD} \times 0.052) = \text{Pressure}$$

Now move the Mud Weight across and you're back on track

$$\text{TVD} \times 0.052 = \text{Pressure} \div \text{Mud Weight}$$

$$\text{TVD} = \text{Pressure} \div \text{Mud Weight} \div 0.052$$

OR

$$\text{Mud Weight} = \frac{\text{Pressure}}{\text{TVD} \times 0.052}$$

$$3 = \frac{30}{2 \times 5}$$

$2 = 30 \div 3 \div 5$ which gives

$$\text{TVD} = \text{Pressure} \div \text{Mud Weight} \div 0.052$$

A QUICK REFRESHER

Whew - that's been a bit of a session! It has probably been **the** key session. If you have a handle on everything we've covered since we looked at figuring out the order of a calculation then you've pretty much got a handle on calculations. Well done. Let's pause to refresh some of the key points.

The order in which a calculation should be done is:

1) Do anything inside brackets first
2) Square anything that needs squaring
3) Do any multiplications and divisions
4) Add and subtract

If you have a complex formula with calculations above and below the line you must complete those calculations first.

A formula is a set of instructions telling you how to do a calculation.

Questions involving formulas are problem-solving exercises. You will be given some information and a formula to work out an answer. Your task is to get the information into the correct place in the formula and then to carry out the calculation in the correct order.

Most of the time you will only be doing one of four things - adding, subtracting, multiplying or dividing.

If you have to rearrange a formula take it in stages moving things as follows:

If on the original side you	then when it changes side you must
add the number	subtract the number
subtract the number	add the number
multiply by the number	divide by the number
divide by the number	multiply by the number

Use some basic numbers to rearrange a formula if that works better for you.

Write everything down - use lots of space on the page - keep it clear.

CONVERTING UNITS

Last topic before the Chapter Test and the good news is that compared to the bit you've just mastered this one's a breeze!

We measure lots of things in drilling with length, volume, weight (or density) and pressure being four of the main ones. However, we measure them in different ways depending on where we are working or who we are working for.

Length can be measured in feet, inches, metres and centimetres.

We measure volume in even more ways; Gallons, Imperial Gallons, Barrels, Cubic Feet, Cubic Metres, Litres,........and so the list goes on.

Density can be measured in ppg, SG, psi/ft, pcf, Bar/metre, KG/metre^3 etc.

At the end of the day they are all just different ways of describing a measured amount of something. The amount is still the same.

One US Dollar could also be described as being 100 US Cents. We have converted it from Dollars into Cents using a conversion factor of 100.

That US Dollar will not do you much good if you were to try to spend it in Scotland where the currency is Pounds Sterling. You need to change it.

At the time of writing One US Dollar equalled 0.64 Pounds Sterling. This is a conversion factor that will allow you to convert any number of US Dollars to Pounds Sterling. You do it by multiplying the US Dollars by the conversion factor to get the Pounds Sterling.

How many Pounds Sterling are 85 US Dollars worth?

$$85 \times 0.64 = £54.40$$

The conversion factor can also be used to convert Pounds Sterling to US Dollars - this time you divide the Pounds Sterling by the conversion factor to get US Dollars.

$$54.40 \div 0.64 = \$85$$

Units used in drilling operations can easily be changed from one to another by using conversion tables. These will be readily available in a number of different sources on the rig. You may even have some in your tally book.

Use this conversion table to answer the questions below.

To convert from left to right multiply by conversion factor		
To convert from right to left divide by conversion factor		
Unit	**Conversion Factor**	**Unit**
Bars	14.5	psi
Feet	0.3048	Metres
ppg	0.1198	SG
Barrels	0.15897	Cubic Metres
Gallons	0.02381	Barrels

a) How many Cubic Metres are there in 25 Barrels? (2 decimal places)

b) How many Bars equal 500 psi? (1 decimal place)

c) How deep is a 12,500 Feet well in Metres? (whole Metres)

d) A mud density of 1.76 SG is how many ppg? (1 decimal place)

e) How may Gallons in 0.38 Cubic Metres (whole Gallons)

ANSWERS

a) How many Cubic Metres are there in 25 Barrels? (2 decimal places)

25 x 0.15897 = 3.9675 = 3.97 m^3

---

b) How many Bars equal 500 psi? (1 decimal place)

500 ÷ 14.5 = 34.48275862 = 34.5 Bars

---

c) How deep is a 12,500 Feet well in Metres? (whole Metres)

12,500 x 0.3048 = 3,810 m

---

d) A mud density of 1.76 SG is how many ppg? (1 decimal place)

1.76 ÷ 0.1198 = 14.69115191 = 14.7 ppg

---

e) How may Gallons in 0.38 Cubic Metres (whole Gallons)

Cubic Metres will have to be converted to Barrels first and then the Barrels converted to Gallons.

0.38 ÷ 0.15897 = 2.390388123 Barrels

2.390388123 ÷ 0.02381 = 100.3942932 = 100 Gallons

CHAPTER TEST TIME

Well, almost test time anyway. On the following pages there are some questions based on everything you have covered. If you have worked through this chapter properly, ensuring you understand everything and covering things again you've not been sure of, then this final test will not trouble you.

You will be asked to put all the skills you have learned into practice during the test. As a refresher these have been:

Fractions and decimals
Squaring a number
Percentages
Rounding your answers
Figuring out the order of a calculation
Using and rearranging Formulas
Converting Units

If you see anything in this list that you're not sure about then go back and have another look before you start the test.

This test is for you to find out how you have done. Do it honestly under test conditions. There are fully worked out answers after the test. These are there so you can mark your own test and also to see how the calculations should be done if you get any wrong. Do not look at the answers until you have finished the test. You'll only be cheating yourself if you do.

So, time to get ready. Check your calculator is working. Have pen or pencil ready. Make sure you have plenty of blank paper. Number each question. Use lots of space and keep your working out clear. Remember to add the unit to the final answer.

Remember we have only covered the calculation skills in this chapter. You may not understand what the terms mean but you will still be able to do the test. We will deal with what things mean in the remaining chapters in this book.

Take your time - this is not against the clock.

Good luck - but luck doesn't really come into it.

CHAPTER TEST

Data:

Well Depth (TVD) = 14,650 ft
Current Mud Weight = 14.5 ppg
LOT Pressure = 1,700 psi
Drill Pipe Length = 13,300 ft
D = 12 $^1/_2$ "

Shoe TVD = 9,780 ft
Test Mud Weight = 12.3 ppg
SIDPP = 720 psi
Pump Output = 0.117 bbl/stk
d = 9 $^1/_4$ "

Formulas:

Strokes = Volume (bbls) ÷ Pump Output (bbl/stk)

Max Mud Weight (ppg) = (LOT Pressure (psi) ÷ 0.052 ÷ Shoe TVD (ft)) + Test Mud Weight (ppg)

Hydrostatic Pressure (psi) = Current Mud Weight (ppg) x 0.052 x Well TVD (ft)

MAASP (psi) = (Max Mud Weight (ppg) - Current Mud Weight (ppg)) x 0.052 x Shoe TVD (ft)

$$\text{Kill Mud Weight (ppg)} = \frac{\text{SIDPP (psi)}}{\text{Well TVD (ft)} \times 0.052} + \text{Current Mud Weight (ppg)}$$

$$\text{Annular Capacity (bbl/ft)} = \frac{D^2 - d^2}{1029.4}$$

Conversion Table:

To convert from left to right multiply by conversion factor		
To convert from right to left divide by conversion factor		
Unit	**Conversion Factor**	**Unit**
Bars	14.5	psi
Feet	0.3048	Metres
ppg	0.1198	SG

Using the data, formulas and conversion table opposite, along with the information given in each question, answer the following questions, rounding your answer as detailed:

1) What percentage of the total well depth will the drill pipe take up? (nearest whole percentage)

2) It takes 4,150 strokes to circulate a hole clean. What is the well volume in Barrels (bbl)? (two decimal places)

3) What is the annular capacity? (four decimal places)

4) What is MAASP? (nearest whole psi)

5) What is the Kill Mud Weight? (one decimal place)

6) The well has been cased to the Shoe. From the Shoe to TVD is Open Hole. How long is the Open Hole section in metres? (one decimal place)

7) Work out how many strokes there will be to the nearest whole stroke if:

   D = 8 $^1/_2$", d = 6 $^1/_4$", Length is 840 feet and the Formula for Volume is:

   Volume (bbl) = Annular Capacity (bbl/ft) x Length (ft)

8) What is the Hydrostatic Pressure in Bar? (one decimal place)

9) You need 382 Gallons of Fluid to operate the BOP. The contract states you must have an additional 14%. How many Gallons will be needed to meet the contract requirements? (whole gallons)

10) Rearrange this formula to work out Annular Capacity?

    Annular Velocity = Pump Output ÷ Annular Capacity

ANSWERS

1) What percentage of the total well depth will the drill pipe take up? (nearest whole percentage)

13300 ÷ 14650 % gives 90.78498293

= 91%

---

2) It takes 4,150 strokes to circulate a hole clean. What is the well volume in Barrels (bbl)? (two decimal places)

Strokes = Volume (bbls) ÷ Pump Output (bbl/stk)

Strokes x Pump Output (bbl/stk) = Volume (bbls) flipped to give

Volume (bbls) = Strokes x Pump Output (bbl/stk)

OR rearrange the formula using basic numbers:

Strokes = Volume (bbls) ÷ Pump Output (bbl/stk)

4 = 8 ÷ 2

8 = 4 x 2 which is

Volume (bbls) = Strokes x Pump Output (bbl/stk)

= 4,150 x 0.117

= 485.55 bbl

3) What is the annular capacity? (four decimal places)

$$\text{Annular Capacity (bbl/ft)} = \frac{D^2 - d^2}{1029.4}$$

$D = 12\ ^1/_2\ " = 12.5$ $\qquad$ $d = 9\ ^1/_4\ " = 9.25$

$$\text{Annular Capacity (bbl/ft)} = \frac{12.5^2 - 9.25^2}{1029.4}$$

$$\text{Annular Capacity (bbl/ft)} = \frac{156.25 - 85.5625}{1029.4}$$

$$\text{Annular Capacity (bbl/ft)} = \frac{70.6875}{1029.4}$$

Annular Capacity = 0.068668641

= 0.0687 bbl/ft

The calculation can also be done using the memory function as follows:

9.25 x = M+ C 12.5 x = - MR = ÷ 1029.4 = to give you 0.068668641

4) What is MAASP? (nearest whole psi)

MAASP (psi) = (Max Mud Weight (ppg) - Current Mud Weight (ppg)) x 0.052 x Shoe TVD (ft)

Max Mud Weight has not been given in the Data so will need to be worked out first.

Max Mud Weight (ppg) = (LOT Pressure (psi) ÷ 0.052 ÷ Shoe TVD (ft)) + Test Mud Weight (ppg)

Max Mud Weight (ppg) = (1,700 ÷ 0.052 ÷ 9,780) + 12.3

= 3.342771747 + 12.3

= 15.64277174

There are no rounding instructions for this one but seeing as all other mud weights are to one decimal place that would be OK therefore meaning:

Max Mud Weight = 15.6 ppg

MAASP (psi) = (Max Mud Weight (ppg) - Current Mud Weight (ppg)) x 0.052 x Shoe TVD (ft)

MAASP = (15.6 - 14.5) x 0.052 x 9,780

= 1.1 x 0.052 x 9,780

= 559.416

= 559 psi

5) What is the Kill Mud Weight? (one decimal place)

$$\text{Kill Mud Weight (ppg)} = \frac{\text{SIDPP (psi)}}{\text{Well TVD (ft)} \times 0.052} + \text{Current Mud Weight (ppg)}$$

$$= \frac{720}{14{,}650 \times 0.052} + 14.5$$

$$= \frac{720}{761.8} + 14.5$$

$= 0.945129955 + 14.5$

$= 15.44512995$

$= 15.4$ ppg

This one can also be done using the memory function:

14650 x 0.052 = M+ C 720 ÷ MR = + 14.5 = to give you 15.44512995

---

6) The well has been cased to the Shoe. From the Shoe to TVD is Open Hole. How long is the Open Hole section in metres? (one decimal place)

Open Hole Length = 14,650 - 9,780

= 4,870 ft

Convert this to metres

4,870 x 0.3048

= 1484.376

= 1484.4 m

7) Work out how many strokes there will be to the nearest whole stroke if:

D = 8 $^1/_2$", d = 6 $^1/_4$", Length is 840 feet and the Formula for Volume is:

Volume (bbl) = Annular Capacity (bbl/ft) x Length (ft)

The formula for strokes is:

Strokes = Volume (bbls) ÷ Pump Output (bbl/stk)

We must first work out Volume using the formula given in the question.

Volume (bbl) = Annular Capacity (bbl/ft) x Length (ft)

Before we can work out volume we need to work out Annular Capacity.

$$\text{Annular Capacity (bbl/ft)} = \frac{D^2 - d^2}{1029.4}$$

D = 8 $^1/_2$ " = 8.5 and d = 6 $^1/_4$ " = 6.25

$$\text{Annular Capacity} = \frac{8.5^2 - 6.25^2}{1029.4}$$

$$= \frac{72.25 - 39.0625}{1029.4}$$

$$= \frac{33.1875}{1029.4}$$

= 0.032239654 to four decimals as before is

= 0.0322 bbl/ft

Answer continued opposite:

We can now use this to work out the Volume:

Volume (bbl) = Annular Capacity (bbl/ft) x Length (ft)

= 0.0322 x 840

= 27.048 bbl

which can now be used to work out strokes:

Strokes = Volume (bbls) ÷ Pump Output (bbl/stk)

= 27.048 ÷ 0.117

= 231.1794871

= 231 stk

---

8) What is the Hydrostatic Pressure in Bar? (one decimal place)

Hydrostatic Pressure (psi) = Current Mud Weight (ppg) x 0.052 x Well TVD (ft)

= 14.5 x 0.052 x 14,650

= 11,046.1 or in whole psi

= 11,046 psi

Convert psi to Bar:

11,046 ÷ 14.5

= 761.7931034

= 761.8 Bar

9) You need 382 Gallons of Fluid to operate the BOP. The contract states you must have an additional 14%. How many Gallons will be needed to meet the contract requirements? (whole gallons)

382 + 14%

= 435.48

= 435 Gal

---

10) Rearrange the formula to work out Annular Capacity?

Annular Velocity = Pump Output ÷ Annular Capacity

Annular Velocity x Annular Capacity = Pump Output

Annular Capacity = Pump Output ÷ Annular Velocity

OR using some basic numbers:

Annular Velocity = Pump Output ÷ Annular Capacity

4 = 8 ÷ 2

2 = 8 ÷ 4

Annular Capacity = Pump Output ÷ Annular Velocity

FINAL SCORE

Use the marking table below to score how well you did in the chapter test.

Question	Answer	Correct or Incorrect	Value	Your Score
1	91%		2	
2	485.55 bbl		4	
3	0.0687 bbl/ft		4	
4	559 psi		5	
5	15.4 ppg		2	
6	1,484.4 m		3	
7 (for annular capacity)	0.0322 bbl/ft		4	
7 (for strokes)	231 stk		4	
8	761.8 bar		3	
9	435 gal		2	
10	See Answer		2	
Total Score Available = 35 Points			Your Total Score	

Your Score = ________ ÷ 35 x 100 = [%]

Round to the nearest whole percentage. If you scored 70% or above then you passed.

LAST WORD

So you made it to the end of chapter one - well done.

This has probably been the toughest chapter in the book.

In completing this chapter you have given yourself the calculation skills you will need to complete the remaining three chapters in this book.

The remaining three sections will go on to explain how to use these skills in volume, pressure and well control calculations.

Each chapter will focus on teaching the topic and not on how to do the calculations.

The remaining chapters will assume that you know the order in which a calculation should be performed.

The remaining chapters will assume that you know how to round a number.

The remaining chapters will assume that you can rearrange a formula.

The remaining chapters will assume you know to write everything down, clearly and in space.

The remaining chapters will assume that you have a handle on calculations.

Good luck with the next chapter - Volume Calculations.

Don’t wait too long before starting.

NOTES

CHAPTER 2
VOLUME CALCULATIONS

This chapter of the book moves on to cover many of the volume related calculations you will come across on a drilling rig and in particular those related to well control. It starts slowly building a basic picture of volume before focusing on some practical field applications. Topics covered include:

- Pit volume
- String and hole volume
- Annular volume
- Pump output
- Stroke and time calculations
- Annular velocity
- Capacities and displacements
- Trip sheet calculations
- Kill sheet - volume calculations

There is a final chapter test at the end to check you understanding.

D. Cormack, *An Introduction to Well Control Calculations for Drilling Operations*, DOI 10.1007/978-3-319-63190-5_2

DON'T PANIC

Welcome to the second chapter in the Introduction to Well Control Calculations for Drilling Operations.

This time we are going to look at using the skills you learned in the first chapter in some volume calculations. Having successfully completed the first chapter you should have no problems with the calculations. You will be able to concentrate on learning how they relate to volumes and where they are used.

This chapter is laid out exactly as the first one was. There are a number of lessons which make up a subject. Each lesson will be no more than two pages long which means you always have a complete lesson to view. You never need to turn the page to complete a learning point.

There are worked examples - go through them using your own calculator to see how they work. There are a number of calculations for you to try yourself. Make sure you do them all.

Fully worked-out answers are given for each question - make sure you try the questions before looking at the answers.

When working out calculations remember to write them down ensuring everything is clearly written and identified. Write down all the stages of a calculation, including the final answer with its correct unit.

By the time you have completed this chapter, and done so honestly, you will be ready for the third chapter which introduces pressure calculations. You will only be able to do this, though, if you:

Take your time. **Do not skip anything.** **Read every word.**

Do every calculation.

A QUICK REFRESHER

Before you start on volume calculations it is worth quickly refreshing what you learned in the first chapter. The subjects that were covered included:

Fractions and decimals
Squaring a number
Percentages
Rounding your answers
Figuring out the order of a calculation
Using and rearranging formulas
Converting units

You will need to be ably to apply all these calculation skills when working with volumes. Here are a few to get you warmed up. The answers, as always, are over the page.

a) BHCP = Hydrostatic Pressure + APL.

How would you work out APL?

b) Use the following data to work out MAASP to the nearest whole psi.

TVD = 12,689 ft	Shoe TVD = 9,700 ft
Test Mud Weight = 11.8 ppg	Current Mud Weight = 14.7 ppg
LOT Pressure = 1,950 psi	Max Mud Weight = 15.6 ppg

MAASP (psi) = (Max Mud Weight (ppg) - Current Mud Weight (ppg)) x 0.052 x Shoe TVD (ft)

c) What would be the volume in bbls if you added an extra 18%? Work this out to the nearest whole bbl.

Strokes = 3,650	Pump Output = 0.119 bbl/stk

Strokes = Volume (bbl) ÷ Pump Output (bbl/stk)

ANSWERS

a) BHCP = Hydrostatic Pressure + APL.

How would you work out APL?

BHCP = Hydrostatic Pressure + APL

BHCP - Hydrostatic Pressure = APL flipped to give

APL = BHCP - Hydrostatic Pressure

OR by using a simple calculation to rearrange the formula

BHCP = Hydrostatic Pressure + APL

10 = 6 + 4

4 = 10 - 6

APL= BHCP - Hydrostatic Pressure

---

b) Use the following data to work out MAASP to the nearest whole psi.

TVD = 12,689 ft
Test Mud Weight = 11.8 ppg
LOT Pressure = 1,950 psi
Shoe TVD = 9,700 ft
Current Mud Weight = 14.7 ppg
Max Mud Weight = 15.6 ppg

MAASP (psi) = (Max Mud Weight (ppg) - Current Mud Weight (ppg)) x 0.052 x Shoe TVD (ft)

MAASP = (15.6 - 14.7) x 0.052 x 9,700

= 0.9 x 0.052 x 9,700

= 453.96

= 454 psi

c) What would be the volume in bbls if you added an extra 18%? Work this out to the nearest whole bbl.

Strokes = 3,650 Pump Output = 0.119 bbl/stk

Strokes = Volume (bbl) ÷ Pump Output (bbl/stk)

Strokes x Pump Output (bbl/stk) = Volume flipped to read

Volume (bbls) = Strokes x Pump Output (bbl/stk)

= 3,650 x 0.119

= 434.35

= 434.35 + 18%

= 512.533 which rounds to

= 513 bbl

No real problems with these hopefully.

Write things down before picking up the calculator. This will allow you to plan the calculation before jumping into it.

Work out calculations in stages to help keep them clear.

Take your time - there is no hurry.

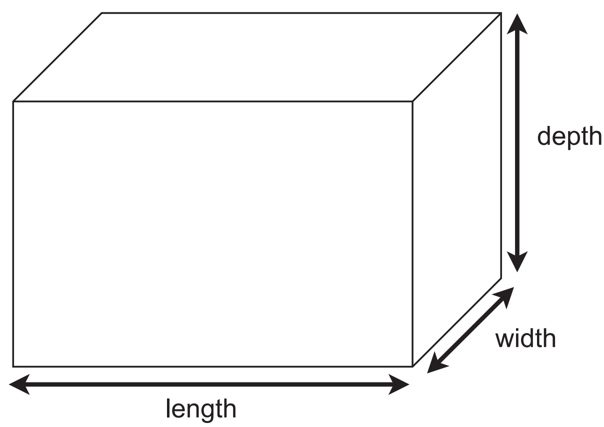
PIT VOLUME

This chapter is going to deal exclusively with volumes. Volume is how much space something takes up. The two main volumes we are concerned with are hole volumes and pit volumes.

We use mud (drilling fluid) for a number of different reasons in our industry with hole cleaning and well control being two of the main ones. We need to know what volume of mud there should be in the hole. This will tell us if we have our well control correct. It can also help us work out things for hole cleaning.

We also need to know how much mud we have in our pits at surface and how much spare capacity we have in our pits at surface.

Generally speaking, a mud pit is a square-sided tank like the one shown below.



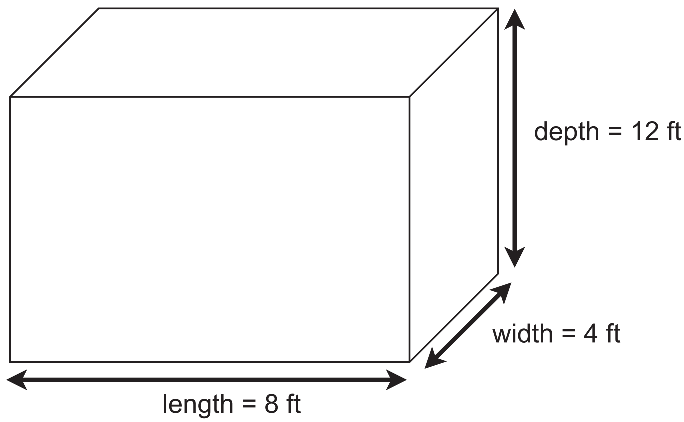
As you can see the pit has length, width and depth, these are its dimensions - how long it is, how wide it is and how deep it is.

If you know what these dimensions are you can work out the volume of the pit simply by multiplying the three figures together:

$$\text{Volume} = \text{Length} \times \text{Width} \times \text{Depth}$$

In order to get a meaningful answer, however, you need to know what units of measurement are being used. If we measured the mud pit dimensions in feet we would be able to work out the volume in cubic feet - ft^3.

Work out the volume in cubic feet for the pit shown below:



Volume (ft^3) = Length (ft) x Width (ft) x Depth (ft)

= 8 x 4 x 12

= 384 ft^3

If the dimensions had been measured in metres what would the volume of the mud pit be? This time the answer will be in cubic metres - m^3

Volume (m^3) = Length (m) x Width (m) x Depth (m)

= 8 x 4 x 12

= 384 m^3

The number is the same - 384 - but the unit is different, m^3 as opposed to ft^3.

In order to work out the volume of a square-sided mud pit you multiply the length by the width by the depth.

If all of the dimensions are in feet you will get an answer in cubic feet.

If all of the dimensions are in metres you will get an answer in cubic metres.

We are going to work mainly in field units through this book. Volumes are usually measured in barrels (bbl). When working out volumes in barrels, answer to two decimal places throughout this book.

In order to convert the answer to barrels you have to use the correct conversion factor.

To convert from left to right multiply by conversion factor		
To convert from right to left divide by conversion factor		
Unit	**Conversion Factor**	**Unit**
Cubic Feet	0.1781	Barrels
Cubic Metres	6.2905	Barrels

Convert 384 ft^3 and 384 m^3 to barrels.

$$384\ ft^3 \times 0.1781 = 68.39\ bbl$$

$$384\ m^3 \times 6.2905 = 2417.28\ bbl$$

As you will see the volume in barrels is very different! Well over 2,300 barrels different!! It is important to use the correct units in a formula. Make sure you check the bit in the brackets.

In field units we normally measure volume in barrels and lengths (& widths & depths) in feet. We can use the conversion factor, 0.1781, as a constant to give us a formula for working out the volume in bbls of any square-sided tank:

Square-sided Tank Volume (bbls) = Length (ft) x Width (ft) x Depth (ft) x 0.1781

Answer the following:

a) What is the volume in barrels of a mud pit with the following dimensions?

Length 14 ft, width 7.5 ft, depth 8 ft

b) What is the volume in barrels of a mud pit with the following dimensions?

Length 2.5 m, width 1.6 m, depth 2.2 m

c) What is the volume in cubic metres of a mud pit with the following dimensions?

Length 4.75 ft, width 2.8 ft, depth 11 ft

d) How many barrels per foot will there be in the following pit?

Length 6.5 ft, width 4 ft, depth 13.75 ft

ANSWERS

a) What is the volume in barrels of a mud pit with the following dimensions?

Length 14 ft, width 7.5 ft, depth 8 ft

Square-sided Tank Volume (bbls) = Length (ft) x Width (ft) x Depth (ft) x 0.1781

= 14 x 7.5 x 8 x 0.1781

= 149.604

= 149.6 bbls

---

b) What is the volume in barrels of a mud pit with the following dimensions?

Length 2.5 m, width 1.6 m, depth 2.2 m

Work out cubic metres and then convert to barrels:

Volume (m^3) = Length (m) x Width (m) x Depth (m)

= 2.5 x 1.6 x 2.2

= 8.8 m^3 now convert to barrels

8.8 x 6.2905

= 55.396

= 55.4 bbls

If you knew the conversion factor from metres to feet you could convert length, width & depth to feet and then use the Volume Formula.

To convert metres to feet you multiply by 3.281. Try it to see what the volume works out to. Convert feet to 2 decimal places.

c) What is the volume in cubic metres of a mud pit with the following dimensions?

Length 4.75 ft, width 2.8 ft, depth 11 ft

Square-sided Tank Volume (bbls) = Length (ft) x Width (ft) x Depth (ft) x 0.1781

= 4.75 x 2.8 x 11 x 0.1781

= 26.1 bbls now convert to cubic metres

26.1 ÷ 6.2905

= 4.15 m^3 ***(from here on in the answer will be rounded by this stage)***

---

d) How many barrels per foot will there be in the following pit?

Length 6.5 ft, width 4 ft, depth 13.75 ft

Sneaky one - we haven't covered this! Work out the volume in barrels then divide it by the depth in feet to find out what volume of mud there will be for every foot in the pit.

Square-sided Tank Volume (bbls) = Length (ft) x Width (ft) x Depth (ft) x 0.1781

= 6.5 x 4 x 13.75 x 0.1781

= 63.67 bbls now divide by pit depth

63.67 ÷ 13.75

= 4.63 bbl/ft

On the rig you will most likely have foot and tenth foot markers in your pits so you can quickly work out how much mud is in any pit. Check it out on your rig when you get a chance.

STRING & HOLE VOLUME

Ok, you can work out the volume of a mud pit quite easily because it is square-sided. It will be a different matter when you have to work out the volume of something that is not square-sided - say, like a round hole in the ground!

We are going to look at open hole volume next - how much mud it will take to completely fill the hole.

Before we look at open hole volume, however, let's take a different look at how we calculated the tank volume.

To start we said that:

Volume = Length x Width x Depth

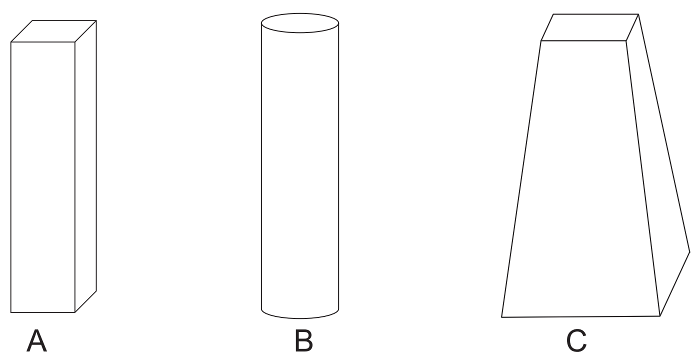
When you multiply Length by Width you get Area.

Area is the size of a flat surface. We could rewrite the volume formula to read:

Volume = Area x Depth

This formula could be used to work out the volume of any three-dimensional space as long as long as it's shape stays the same throughout its length.

The formula could be used to work out the volume of which of the following?



The formula could be used to work out the volumes of A & B but not for C. The good news is that in this book you will not be asked to work out the area for an odd-shaped space!

AREA OF A CIRCLE

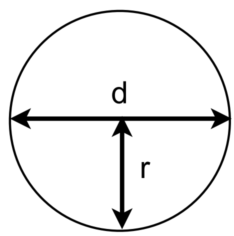
You can work out the volume of any space if you know its area and its depth by using the formula:

Volume = Area x Depth

Given that a hole is round you need to work out the area of a circle to be able to work out hole volume. Over 2,000 years ago a Greek fellow called Archimedes worked out a formula for the area of a circle. He had little else to do other than sit around thinking about things (probably a mud logger to trade!) but he said:

$$\text{Area of a Circle} = (\pi d^2) \div 4$$

where π is the Greek letter pi, which is approximately 3.1416, and d is the diameter of the circle. Pi is how many times the diameter will go around the circumference (the outside of the circle). The diameter is the distance across a circle from one edge to the other in a straight line through the centre. For information, the radius (r) is the distance from the middle to the edge and is half the size of the diameter.



Replacing π with its value the formula could be rewritten as:

$$\text{Area of a Circle} = (3.1416 \times d^2) \div 4$$

or even rearranged mathematically to read:

$$\text{Area of a Circle} = d^2 \times (3.1416 \div 4)$$

3.1416 and 4 are constants so we can do the division to leave us with:

$$\text{Area of a Circle} = d^2 \times 0.7854$$

You will not need to use this formula but knowing how we got it will help with what follows.

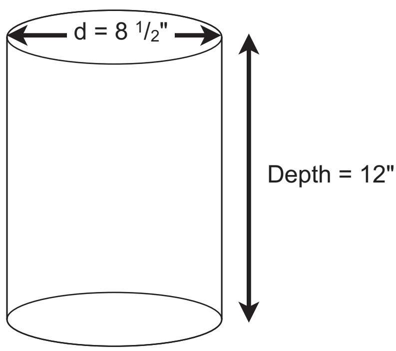
DERIVATION OF 1029.4

Stick with this next bit. You will not have to repeat this in any test but it is worth following as it explains where we get the constant 1029.4 from.

You can work out the volume of any space if you know its area and its depth by using the formula:

$$\text{Volume} = \text{Area} \times \text{Depth}$$

To calculate the volume of a cylinder (which is effectively what a section of open hole is) you must multiply its Area by its Depth. What is the volume of the cylinder shown?



$$\begin{aligned}\text{Volume} &= \text{Area} \times \text{Depth} \\ &= d^2 \times 0.7854 \times \text{Depth} \\ &= 8.5^2 \times 0.7854 \times 12 \\ &= 72.25 \times 0.7854 \times 12 \\ &= 680.94 \text{ in}^3\end{aligned}$$

We have just worked out the volume of this cylinder in cubic inches - we use inches as our measurement for diameters, after all.

We use inches for diameter and feet for length so if we wanted to know the volume in cubic feet we would have to divide our answer by 144 (12 x 12, which is the number of square inches in a square foot).

So the formula could be written:

$$\text{Volume of Cylinder (ft}^3\text{)} = (d^2 \text{ (in)} \times 0.7854) \times \text{Depth (in)} \div 144$$

Given we are working in field units then we measure volume in barrels. To convert cubic feet to barrels you multiply by the conversion factor 0.1781. This gives us a formula that reads:

$$\text{Volume of Cylinder (bbls)} = (d^2\text{ (in)} \times 0.7854) \times \text{Depth (in)} \div 144 \times 0.1781$$

We measure depth in feet and tend to express volume as a capacity in barrels per foot (bbl/ft). This means we can remove Depth (in) from the formula so it reads:

$$\text{Volume of Cylinder (bbl/ft)} = (d^2\text{ (in)} \times 0.7854) \div 144 \times 0.1781$$

Still here hopefully because now comes the clever bit! Let's rearrange the formula so we get all the variables on one side and all the constants on the other:

$\text{Volume of Cylinder (bbl/ft)} = (d^2\text{ (in)} \times 0.7854) \div 144 \times 0.1781$ ***move 144***

$\text{Volume of Cylinder (bbl/ft)} \times 144 = (d^2\text{ (in)} \times 0.7854) \times 0.1781$ ***move 0.1781***

$\text{Volume of Cylinder (bbl/ft)} \times 144 \div 0.1781 = d^2\text{ (in)} \times 0.7854$ ***move 0.7854***

$\text{Volume of Cylinder (bbl/ft)} \times 144 \div 0.1781 \div 0.7854 = d^2\text{ (in)}$ ***move Volume***

$144 \div 0.1781 \div 0.7854 = d^2\text{ (in)} \div \text{Volume of Cylinder (bbl/ft)}$

If we now work out the calculation on the left hand side we get:

$144 \div 0.1781 \div 0.7854 = d^2\text{ (in)} \div \text{Volume of Cylinder (bbl/ft)}$

$1029.4 = d^2\text{ (in)} \div \text{Volume of Cylinder (bbl/ft)}$ ***which rearranges back to***

$1029.4 \times \text{Volume of Cylinder (bbl/ft)} = d^2\text{ (in)}$ ***volume has been moved***

$\text{Volume of Cylinder (bbl/ft)} = d^2\text{ (in)} \div 1029.4$ ***1029.4 has been moved***

This is an important formula in drilling calculations - it is used to work out the capacity of hole sections and also of the drill string.

HOLE CAPACITY

Things ease up a bit now - but on the flip side you have to do more calculations!

We have just worked out the following formula:

$$\text{Volume of Cylinder (bbl/ft)} = d^2\text{ (in)} \div 1029.4$$

A section of hole is a cylinder so we could rename the formula:

$$\text{Hole Capacity (bbl/ft)} = d^2\text{ (in)} \div 1029.4$$

where the small d is the inside diameter (ID) of the hole. For open-hole sections of the well this will be the bit diameter.

What will the hole capacity be if we are drilling with a 12 $^1/_2$" bit?

$$\text{Hole Capacity (bbl/ft)} = d^2\text{ (in)} \div 1029.4$$

$$= 12.5^2 \div 1029.4$$

$$= 156.25 \div 1029.4$$

$$= 12.5^2 \div 1029.4$$

$$= 0.151787448$$

What should this answer be rounded to? Capacities need to be taken to a fair degree of accuracy, as we will see shortly, so we generally go to four or five decimal places. In this case take it to five decimal places:

$$= 0.151787448$$

$$= 0.15179\text{ bbl/ft}$$

The same formula can also be used to work out the capacity of cased-hole sections. In this case you need to know the ID of the casing. This varies depending on the weight per foot of the casing, which is usually measured in pounds per foot (lb/ft). The greater the lb/ft the more steel there will be for a given size of casing, therefore the smaller the ID.

9 5/8" Casing that weighs 32.3 lb/ft has an ID of 9.001". What is the capacity of this casing in bbl/ft. Round to five decimals as before.

$$\text{Hole Capacity (bbl/ft)} = d^2 \text{ (in)} \div 1029.4$$

$$= 9.001^2 \div 1029.4$$

$$= 81.018001 \div 1029.4$$

$$= 0.0787 \text{ bbl/ft}$$

Work out the capacity in bbl/ft of the following cased and open-hole sections to five decimal places.

a) Open-hole section using a 26" bit.

b) Open-hole section using a 17 1/2" bit.

c) Open-hole section using a 12 1/4" bit.

d) Cased-hole section - 18 5/8" casing with an ID of 17.755"

e) Cased-hole section - 9 5/8" casing with an ID of 8.535"

ANSWERS

Hole Capacity (bbl/ft) = d^2 (in) ÷ 1029.4

a) 26^2 ÷ 1029.4 = 676 ÷ 1029.4 = 0.65669 bbl/ft

b) 17.5^2 ÷ 1029.4 = 306.25 ÷ 1029.4 = 0.2975 bbl/ft

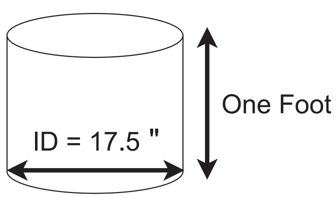
c) 12.25^2 ÷ 1029.4 = 150.0625 ÷ 1029.4 = 0.14578 bbl/ft

d) 17.755^2 ÷ 1029.4 = 315.240025 ÷ 1029.4 = 0.30623 bbl/ft

e) 8.535^2 ÷ 1029.4 = 72.846225 ÷ 1029.4 = 0.07077 bbl/ft

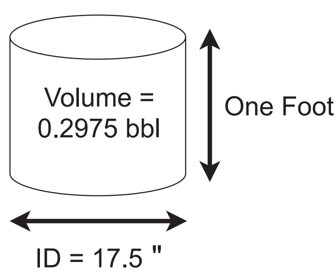
HOLE VOLUME

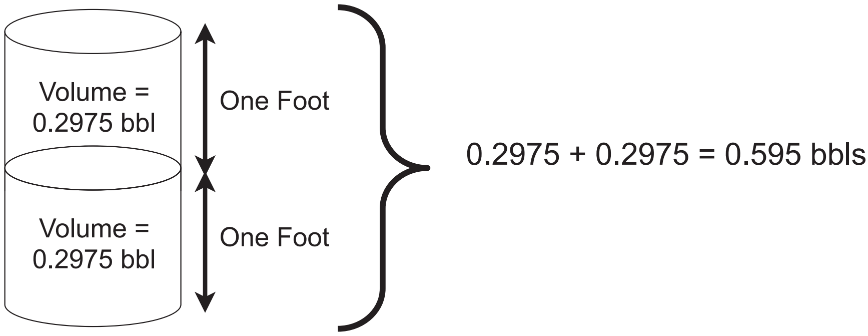
A barrels per foot capacity tells you the volume of one foot of a particular hole section:



The volume to fill this section of hole is 0.2975 bbl

What volume would be needed to fill two feet of this hole section?





You can work out the volume for any hole section simply by multiplying the capacity of the section by the length of the section:

$$\text{Hole Volume (bbl)} = \text{Capacity (bbl/ft)} \times \text{Length (ft)}$$

Work out the volume required to fill the following sections of hole. All volumes in barrels should be rounded to two decimal places.

a) 1,500 ft long open-hole section with a capacity of 0.65669 bbl/ft.

b) Open-hole section that is 3,782 ft long with a capacity of 0.14578 bbl/ft.

c) Cased-hole section that is 7,896 ft long with a capacity of 0.07077 bbl/ft.

d) We have used an 8 $^1/_2$" bit to drill an open-hole section of 2,768 ft. How much mud is required to fill the open-hole section?

e) We have run 13 $^3/_8$" casing (ID = 12.515") to a depth of 8,246 ft. How much mud is required to fill the casing?

ANSWERS

Hole Volume (bbls) = Capacity (bbl/ft) x Length (ft)

a) 0.65669 x 1,500 = 985.03 bbl

---

b) 0.14578 x 3,782 = 551.34 bbl

---

c) 0.07077 x 7,896 = 558.8 bbl

---

d) First work out capacity: Hole Capacity (bbl/ft) = d^2 (in) ÷ 1029.4

= $8.5^2 \div 1029.4$

= 72.25 ÷ 1029.4 = 0.07019 bbl/ft

Hole Volume (bbls) = Capacity (bbl/ft) x Length (ft)

= 0.07019 x 2,768 = 194.86 bbl

---

e) Capacity = $12.515^2 \div 1029.4$

= 156.625225 ÷ 1029.4 = 0.15215 bbl/ft

Hole Volume (bbls) = Capacity (bbl/ft) x Length (ft)

= 0.15215 x 8,246 = 1,254.63 bbl

STRING CAPACITY

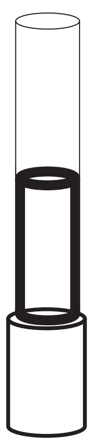
The bit is run to the bottom of the hole on the Drill String. The drill string is usually made up of Drill Pipe, Hevi Weight Drill Pipe (HWDP) and the Bottom Hole Assembly (BHA).

The BHA can have many different components in it such as stabilisers, subs, motors, jars etc with the main component usually Drill Collars. For the sake of simplicity when working out volume calculations we are going to assume that the entire BHA is Drill Collars. The margin of error is so small that it can be safely ignored.

All the components of the drill string are hollow pipe. We need to be able to pump mud down the inside of the drill string in order to be able to do a number of things. The drill string is in effect a number of cylinders connected together. If we know the ID of the drill string component we can work out its capacity in bbl/ft using the same formula we used for hole capacity:

$$\text{String Capacity (bbl/ft)} = d^2 \text{ (in)} \div 1029.4$$

Work out the capacity, in bbl/ft, of the following sections of drill string:



a) 5" OD Drill Pipe with an ID of 4.276"

b) 5" OD HWDP with an ID of 3"

c) 6 $^3/_4$" OD Drill Collars with an ID of 2.8125"

ANSWERS

String Capacity (bbl/ft) = d^2 (in) ÷ 1029.4

a) $4.276^2 \div 1029.4 = 18.284176 \div 1029.4 = 0.01776$ bbl/ft

b) $3^2 \div 1029.4 = 9 \div 1029.4 = .00874$ bbl/ft

c) $2.8125^2 \div 1029.4 = 7.91015625 \div 1029.4 = .00768$ bbl/ft

STRING VOLUME

By now you will have figured out that the next thing you can do with this information is calculate how much mud will be required to fill the drill string. You need to know the lengths of each section of the drill string to be able to do this.

Using the previous examples let's see what volume will be required to fill the drill string if we have 7,000 ft of drill pipe, 980 ft of HWDP and 650 ft of drill collars.

String Volume (bbl) = Capacity (bbl/ft) x Length (ft)

Drill Pipe Volume = 0.01776 x 7,000 = <u>124.32 bbl</u>

HWDP Volume = 0.00874 x 980 = <u>8.57 bbl</u>

Drill Collar Volume = 0.00768 x 650 = <u>4.99 bbl</u>

To work out total drill string volume you need to add together the volumes of the three sections:

Total String Volume = 124.32 + 8.57 + 4.99 = <u>137.88 bbl</u>

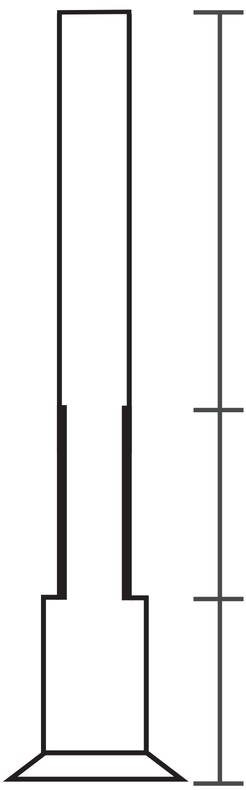
Notice how the section volumes have been underlined, as has the final answer. As questions have more parts this is a good way of identifying key answers.

A drawing of the drill string is very useful when tackling this type of problem as it will help you clearly see where everything is. The drawing does not need to be to scale - it just needs to be clearly set out and labelled.

What is volume of the following drill string - 4,700 ft of drill pipe, 820 ft of HWDP and 715 ft of drill collars? We will use the drill string capacities opposite.

Start off with a simple drawing of a drill string. Opposite the relevant section work out the volume then add up all the sections at the bottom.

String Volume (bbl) = Capacity (bbl/ft) x Length (ft)



Drill Pipe Volume

0.01776 x 4,700 = 83.47 bbl

HWDP Volume

0.00874 x 820 = 7.17 bbl

Drill Collar Volume

0.00768 x 715 = 5.49 bbl

Total Drill String Volume = 83.47 + 7.17 + 5.49 = 96.13 bbl

Open-hole capacity and drill string capacity, in barrels per foot, can be worked out using the same formula:

$$\text{Capacity (bbl/ft)} = d^2 \text{ (in)} \div 1029.4$$

Total volume in barrels can be worked out by multiplying the capacity by the length of the section:

$$\text{Volume (bbl)} = \text{Capacity (bbl/ft)} \times \text{Length (ft)}$$

A simple drawing of the drill string can help with the problem solving.

Using the page opposite (or a blank sheet if you prefer) draw a picture of a drill string and work out how much mud will be required to fill it.

Drill String Data

Well Measured Depth = 14,890 ft

Drill Pipe: 5" OD, ID of 4.408"

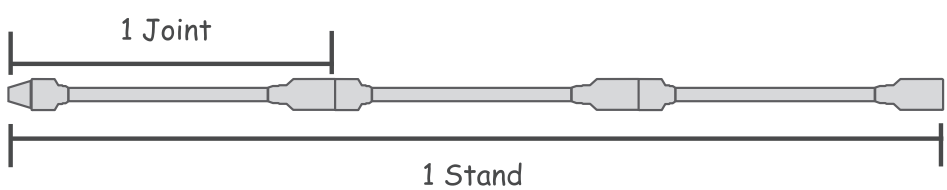
HWDP: 5" OD, ID of 2 $^3/_4$"

Drill Collars: 5 $^3/_4$" OD, ID of 1 $^3/_4$"

Each joint of drill collars is 29 ft long. Each joint of HWDP is 32 ft long. There are 7 stands of drill collars and 12 stands of HWDP. The remainder of the drill string is made up of drill pipe. The bit is on bottom.

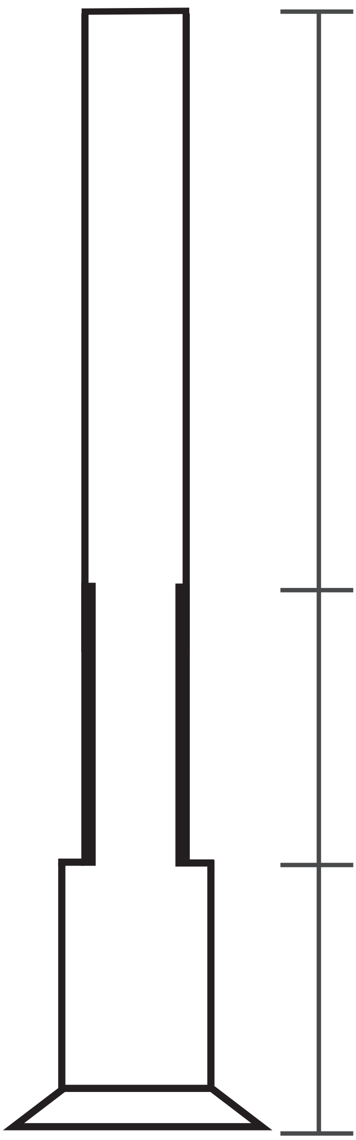
Attention Mud Loggers:

A joint is a single length of pipe - *OK!* Three joints make up a stand. See below:



ANSWERS

You first need to work out the lengths of the Drill Collars and HWDP. Subtract both of these from the Well Measured Depth to get the length of the Drill Pipe. I always start at the bottom and work up.



<u>Drill Pipe</u>

Length = 14,890 - 609 - 1,152 = 13,129 ft

Capacity = $4.408^2 \div 1029.4$ = 0.01888 bbl/ft

Volume = 0.01888 x 13,129 = <u>247.88 bbl</u>

<u>HWDP</u>

Length = 32 x 3 x 12 = 1,152 ft

Capacity = $2.75^2 \div 1029.4$ = 0.00735 bbl/ft

Volume = 0.00735 x 1,152 = <u>8.47 bbl</u>

<u>Drill Collars</u>

Length = 29 x 3 x 7 = 609 ft

Capacity = $1.75^2 \div 1029.4$ = 0.00298 bbl/ft

Volume = 0.00298 x 609 = <u>1.81 bbl</u>

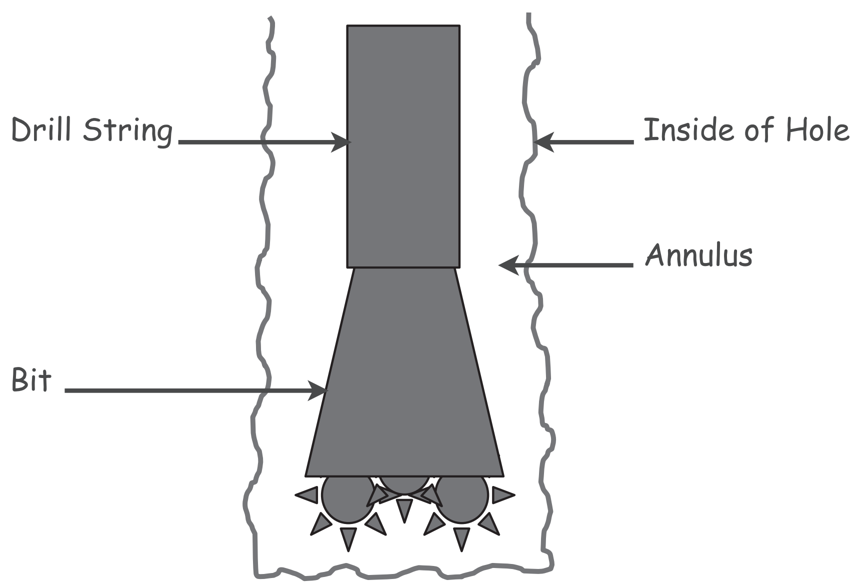
Total Drill String Volume = 247.88 + 8.47 + 1.81 = <u>258.16 bbl</u>

ANNULAR VOLUMES

You can now work out open-hole, cased-hole & string capacities and volumes. Throughout these books the term capacity means barrels per foot (bbl/ft) and the term volume means barrels (bbl).

In the field and other reference manuals they are sometimes used the other way round. Always look for the unit (the bit in brackets) as this will tell you what you are dealing with.

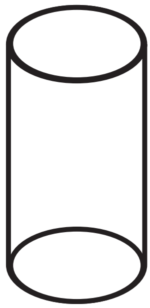
By pumping the mud down the drill string you have it at the bit. It will come out the bit and to get it back to surface you have to pump it up the annulus. This is the space between the outside of the drill string and the inside of the hole or casing.



How do you work out the capacity of the annulus?

Have a think about it before turning the page.

A section of hole, whether open or cased, is a cylinder.



The capacity of this cylinder is:

Capacity (bbl/ft) = D^2 (in) ÷ 1029.4

where D is the ID of the cylinder

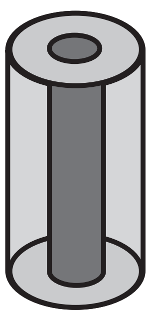
If our drill string was solid it would also be a cylinder.

The capacity of this cylinder is:

Capacity (bbl/ft) = d^2 (in) ÷ 1029.4

where d is the OD of the cylinder. Here we are working out the displacement capacity of the cylinder.

If we put one cylinder inside the other we create a space between them - an annular space.



We could say the annular capacity is:

Annular Capacity (bbl/ft) = (D^2 ÷ 1029.4) - (d^2 ÷ 1029.4)

where the first calculation is for the hole section and the second one is for the string.

This formula can be tidied up to read:

Annular Capacity (bbl/ft) = (D^2- d^2) ÷ 1029.4

We can now take this formula to the rig to work out the annular capacities for any section of the well.

We need to know the ID of the particular section of the well which we call D (Big D as it is known) and the OD of the drill string component (let's use the term tubular from here on in) which we call d (or little d).

The formula can also be written like this:

$$\text{Annular Capacity (bbl/ft)} = \frac{D^2 - d^2}{1029.4}$$

You used this version in the first section of this book and you do the calculation exactly the same way. In this book the formula will always be given the way we just worked it out:

$$\text{Annular Capacity (bbl/ft)} = (D^2 - d^2) \div 1029.4$$

Work out the annular capacities in the following sections of a well. Round to four decimal places.

a) 6 $^5/_8$" OD drill pipe in 12 $^1/_4$" open hole.

b) 6 $^1/_4$" OD drill collar in 8 $^1/_2$" open hole.

c) 5" OD drill pipe in 9 $^5/_8$" casing (ID - 8.755").

d) 3 $^1/_2$" OD drill pipe in 7" casing (ID - 6.276").

ANSWERS

Annular Capacity (bbl/ft) = $(D^2 - d^2) \div 1029.4$

a) $(12.25^2 - 6.625^2) \div 1029.4$

$= (150.0625 - 43.890625) \div 1029.4$

$=$ <u>0.1031 bbl/ft</u>

Don't forget that memory function on your calculator - the key strokes are:

6.625 x = M+ C 12.25 x = - MR = ÷ 1029.4 = to get 0.103139571

---

b) $(8.5^2 - 6.25^2) \div 1029.4$

$= (72.25 - 39.0625) \div 1029.4$

$=$ <u>0.0322 bbl/ft</u> ***or use the memory***

---

c) $(8.755^2 - 5^2) \div 1029.4$ ***remember Big D is casing ID!***

$= (76.650025 - 25) \div 1029.4$

$=$ <u>0.0502 bbl/ft</u>

---

d) $(6.276^2 - 3.5^2) \div 1029.4$

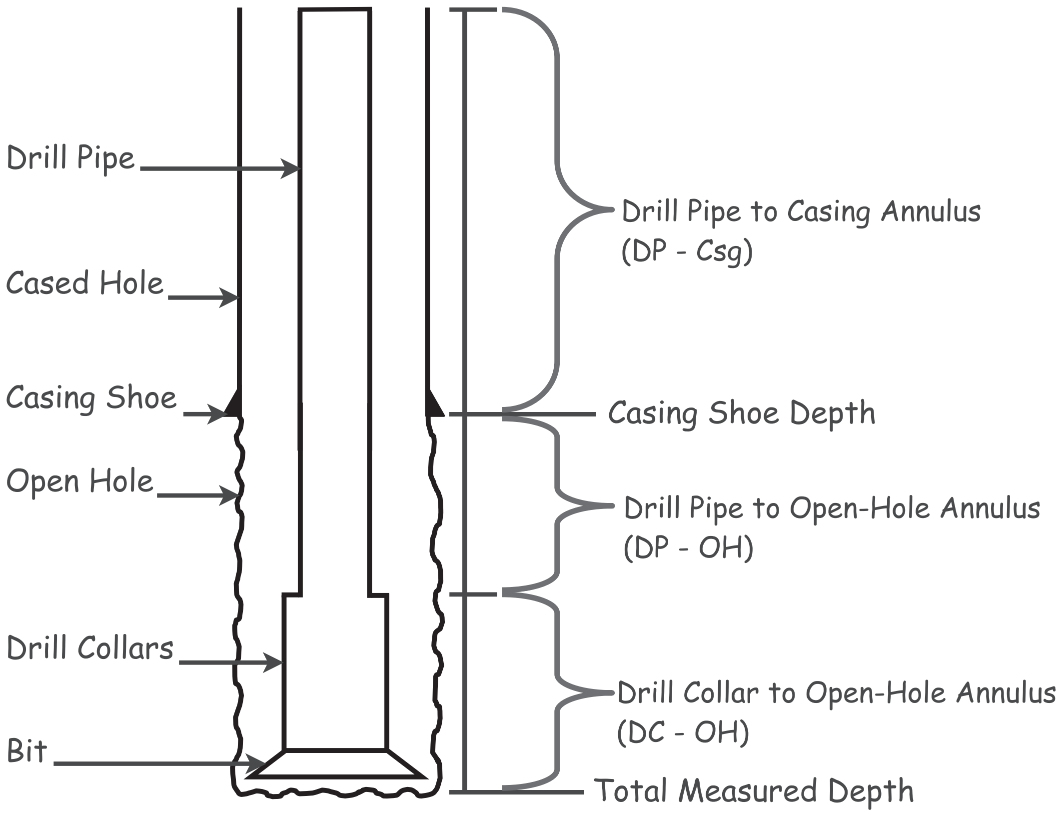
$= (39.388176 - 12.25) \div 1029.4$

$=$ <u>0.0264 bbl/ft</u>

Logically, the next thing we can do is use the annular capacity to work out annular volume using the same formula we used for hole and drill string volumes:

Volume (bbl) = Capacity (bbl/ft) x Length (ft)

As with the drill string volumes a simple drawing can help. This time it will look a bit more complex.



Note there is no HWDP shown in this particular diagram. Through this book where HWDP is used in a question the OD of the HWDP will be the same as the OD of the Drill Pipe therefore the Annular Capacity will be the same. We will ignore the extra length of the tool joint and hard-banding in our volume calculations.

Annular Capacity can be worked out using the formula:

$$\text{Annular Capacity (bbl/ft)} = (D^2 - d^2) \div 1029.4$$

Annular Volume can be worked out using the formula:

$$\text{Volume (bbl)} = \text{Capacity (bbl/ft)} \times \text{Length (ft)}$$

A simple drawing of the well can help with the problem solving.

Using the page opposite (or a blank sheet if you prefer) draw a well schematic and work out how much mud will be required to fill the annulus.

Well Data

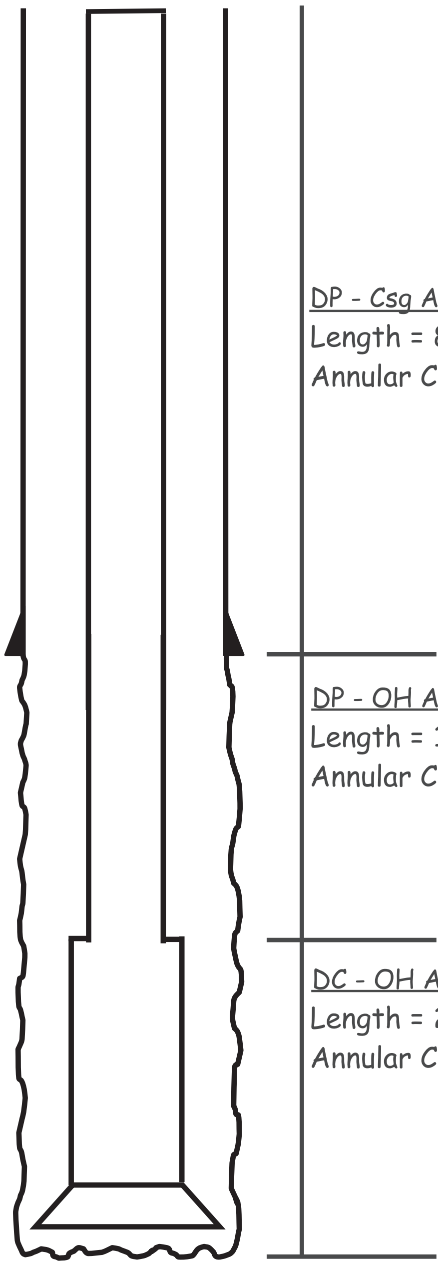
Well Measured Depth = 12,870 ft

Shoe Measured Depth = 8,540 ft

Drill Pipe:	5" OD, ID of 4.408"
Drill Collars:	5 3/4" OD, ID of 1 3/4", 28 ft joints
Casing:	13 3/8" OD, ID of 12.715"
Bit Size:	12 1/4"

There are five stands of drill collars and the bit is on bottom.

ANSWERS



DP - Csg Annulus

Length = 8,540 ft

Annular Capacity $= (12.715^2 - 5^2) \div 1029.4$

$= (161.671225 - 25) \div 1029.4$

$= 0.1328$ bbl/ft

Volume = 0.1328 x 8,540 = 1,134.11 bbl

Shoe Measured Depth - 8,540 ft

DP - OH Annulus

Length = 12,870 - 8,540 - 420 = 3,910 ft

Annular Capacity $= (12.25^2 - 5^2) \div 1029.4$

$= (150.0625 - 25) \div 1029.4$

$= 0.1215$ bbl/ft

Volume = 0.1215 x 3,910 = 475.07 bbl

DC - OH Annulus

Length = 28 x 3 x 5 = 420 ft

Annular Capacity $= (12.25^2 - 5.75^2) \div 1029.4$

$= (150.0625 - 33.0625) \div 1029.4$

$= 0.1137$ bbl/ft

Volume = 0.1137 x 420 = 47.75 bbl

Well Measured Depth - 12,870 ft

Total Annular Volume = 1,134.11 + 475.07 + 47.75 = 1,656.93 bbl

There are a couple of points worth noting here.

Note how the length of the Drill Pipe to Open-Hole Annulus was worked out. Casing Shoe Measured Depth is subtracted away from Well Measured Depth - this will give the total length of the open hole section. The Drill Collar length is then subtracted from that to give the DP-OH annular length.

Also note that the drawing is starting to get very busy and it would be easy to get confused with all the numbers. You need to keep things clear and separate. See how a box has been drawn round the two measured depths to keep them apart from the calculations. Each calculation has been labelled and each answer has been underlined. You could use a highlighter pen if you have one to help with this.

Now it's time to join the two halves together, Drill String and Annulus, to get a complete well calculation. If you do this as one drawing then take care with the drawing as it will be busy! Do the drawing in the middle of the page with the string calculations on one side of it and the annular ones on the other. Alternatively use two drawings.

Well Data

Well Measured Depth = 10,525 ft

Shoe Measured Depth = 7,466 ft

Drill Pipe: $4\ ^1/_2$" OD, ID of 3.958"

HWDP: $4\ ^1/_2$" OD, ID of $2\ ^3/_4$", 31 ft joints

Drill Collars: $6\ ^3/_4$" OD, ID of $3\ ^1/_4$", 28 ft joints

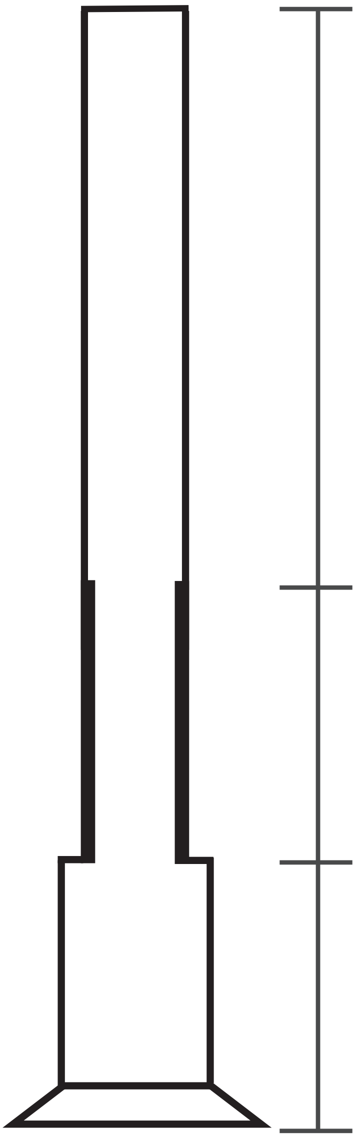
Casing: $9\ ^5/_8$" OD, ID of 8.835"

Bit Size: $8\ ^1/_4$"

There are six stands of drill collars, eight stands of HWDP and the bit is on bottom. What is the total well volume? All capacities to four decimal places.

ANSWERS

DRILL STRING VOLUMES



Drill Pipe

Length = 10,525 - 744 - 504 = 9,277 ft

Capacity = $3.958^2 \div 1029.4$ = 0.0152 bbl/ft

Volume = 0.0152 x 9,277 = 141.01 bbl

HWDP

Length = 31 x 3 x 8 = 744 ft

Capacity = $2.75^2 \div 1029.4$ = 0.0073 bbl/ft

Volume = 0.0073 x 744 = 5.43 bbl

Drill Collars

Length = 28 x 3 x 6 = 504 ft

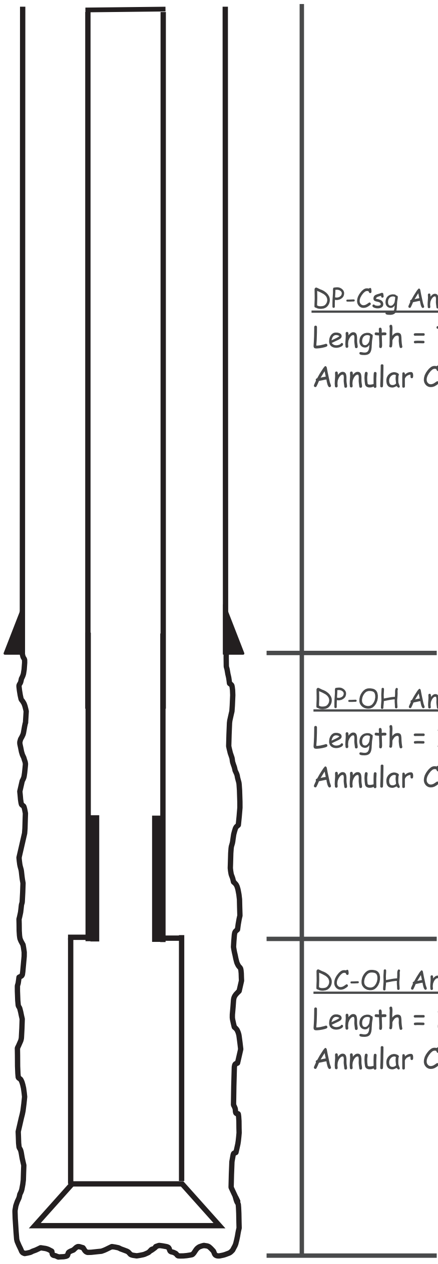
Capacity = $3.25^2 \div 1029.4$ = 0.0103 bbl/ft

Volume = 0.0103 x 504 = 5.19 bbl

Total Drill String Volume = 141.01 + 5.43 + 5.19 = 151.63 bbl

ANSWERS

ANNULAR VOLUMES



DP-Csg Annulus

Length = 7,466 ft

Annular Capacity $= (8.835^2 - 4.5^2) \div 1029.4$

$= (78.057225 - 20.25) \div 1029.4$

$= 0.0562$ bbl/ft

Volume = 0.0562 x 7,466 = 419.59 bbl

Shoe Measured Depth - 7,466 ft

DP-OH Annulus ***(remember DP & HWDP have the same OD)***

Length = 10,525 - 7,466 - 504 = 2,555 ft

Annular Capacity $= (8.25^2 - 4.5^2) \div 1029.4$

$= (68.0625 - 20.25) \div 1029.4$

$= 0.0464$ bbl/ft

Volume = 0.0464 x 2,555 = 118.55 bbl

DC-OH Annulus

Length = 28 x 3 x 6 = 504 ft

Annular Capacity $= (8.25^2 - 6.75^2) \div 1029.4$

$= (68.0625 - 45.5625) \div 1029.4$

$= 0.0219$ bbl/ft

Volume = 0.0219 x 504 = 11.04 bbl

Well Measured Depth - 10,525 ft

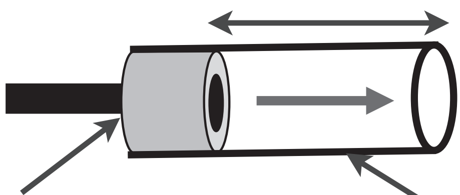
Total Annular Volume = 419.59 + 118.55 + 11.04 = 549.18 bbl

Total Well Volume = 151.63 + 549.18 = 700.81 bbl

PUMP OUTPUT

You now know how to work out drill string and annular volumes. It's time to look at the rig pumps. In this book we will look at the most common type of rig pump used in drilling - the triplex pump.

A pump works by using a tight-fitting piston to force the mud through a liner:



You will have noticed that the pump liner is a cylinder. The capacity of a cylinder can be worked out using the formula:

$$\text{Capacity (bbl/ft)} = d^2 \text{ (in)} \div 1029.4$$

The formula could be used to work out the barrels per foot output of the cylinder where d is the ID of the pump liner. The formula will work if the piston stroke length is one foot (12").

What is the liner output for a pump with a stroke length of 12" and an ID of 6"?

$$\text{Pump Liner Output} = 6^2 \div 1029.4 = \underline{0.035 \text{ bbl}}$$

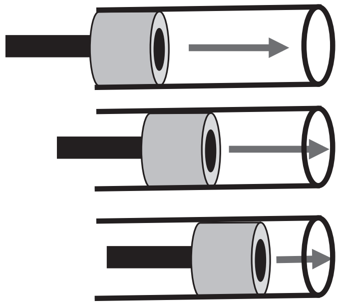
If the piston stroke length is not one foot then you need to multiply the answer by the length in feet.

$$\text{Pump Liner Output (bbl)} = d^2 \text{ (in)} \div 1029.4 \times \text{stroke length (ft)}$$

For instance, if the pump had a 10" stroke you would need to multiply the answer by 0.833 (10 ÷ 12).

$$\text{Pump Liner Output} = 6^2 \div 1029.4 \times 0.833 = \underline{0.029 \text{ bbl}}$$

A Triplex Pump has three liners and pistons all working at the same time.



In field units pump output is expressed as barrels per stroke (bbl/stk). One stroke is completed when all three liners have emptied. Writing this as a formula we get:

Pump Output (bbl/stk) = d^2 (in) ÷ 1029.4 x stroke length (ft) x 3

Using our original information - stroke length of 12" and an ID of 6" - what is the pump output in bb/stk? (3 decimal places)

Pump Output = $6^2 \div 1029.4 \times 1 \times 3$

$= 36 \div 1029.4 \times 1 \times 3 =$ <u>0.105 bbl/stk</u>

You will have noticed that with a 12" the stroke length is 1. When you multiply something by 1 it stays the same so this part could be removed from the calculation and you would still get the same answer:

$6^2 \div 1029.4 \times 3 = 36 \div 1029.4 \times 3 =$ <u>0.105 bbl/stk</u>

What is the pump output in bbl/stk of the following pumps? (3 decimal places)

a) stroke length = 12"; ID = 6 $^1/_2$"
b) stroke length = 8"; ID = 7"
c) stroke length = 12"; ID = 4 $^3/_4$"
d) stroke length = 12"; ID = 5 $^1/_4$"; the pump operates at 97% efficiency
e) stroke length = 10"; ID = 5 $^3/_4$"; the pump operates at 95% efficiency

ANSWERS

Pump Output (bbl/stk) = d^2 (in) ÷ 1029.4 x stroke length (ft) x 3

a) $6.5^2 \div 1029.4 \times 3$ ***(remember a 12" stroke is 1 ft so the x 1 is not needed)***

= 42.25 ÷ 1029.4 x 3 = <u>0.123 bbl/stk</u>

---

b) $7^2 \div 1029.4 \times 0.666 \times 3$ ***(remember 8 ÷ 12 = 0.666)***

= 49 ÷ 1029.4 x 0.666 x 3 = <u>0.095 bbl/stk</u>

---

c) $4.75^2 \div 1029.4 \times 3$

= 22.5625 ÷ 1029.4 x 3 = <u>0.066 bbl/stk</u>

---

d) $5.25^2 \div 1029.4 \times 3$

= 27.5625 ÷ 1029.4 x 3 = 0.08 bbl/stk

Pumps generally do not work at 100% efficiency - you will not get 100% of the theoretical volume discharged - it will be less. You need to work out the percentage:

0.08 x 97% = <u>0.078 bbl/stk</u>

---

e) $5.75^2 \div 1029.4 \times 0.833 \times 3$

= 33.0625 ÷ 1029.4 x 0.833 x 3 = 0.08 bbl/stk

0.08 x 95% = <u>0.076 bbl/stk</u>

DESCRIPTIONS OF THE WELL

There are different terms used to describe different sections of the well. So far we have seen the terms drill string volume and annular volume. When circulating mud we use some others.

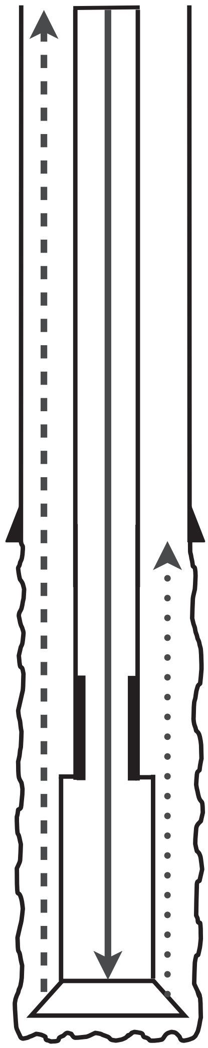
The drill string volume can also be called:

Surface to Bit

This term describes the flow path that the mud will take when it is circulated.

Generally you start at surface and pump mud to the bit.

Surface to Bit is shown as:



Annular volume can also be called:

Bit to Surface OR

Bottoms Up

These terms describe the the flow path the mud takes when it is circulated.

Once mud reaches the bit it is then circulated back up to surface.

Bit to surface (Bottoms Up) is shown as:

There is another term used in the annulus and that is:

Bit to Shoe

The mud travels from the bit to the shoe - this is the Open-Hole section of the Annulus.

Bit to Shoe is shown as:

Be aware of the different terms used.
Think about what the words are saying and visualise it in a well.

STROKE & TIME CALCULATIONS

You now know how to calculate string volume, annular volume and pump output. You also know what the various sections of the well are called.

With this information you can quite easily work out how many strokes will be needed to circulate mud round various sections of the well.

If you know the volume in barrels, and you know how many barrels per stroke you get from your pump, you simply divide the volume by the pump output and you will get the number of strokes required.

The formula for this is:

Strokes = Volume (bbl) ÷ Pump Output (bbl/stk)

If the volume required to fill the Drill String was 180.65 bbls, and the Pump Output was 0.12 bbl/stk, how many strokes (round to nearest whole stroke) would be required to pump mud from surface to bit?

Strokes = Volume (bbl) ÷ Pump Output (bbl/stk)

= 180. 65 ÷ 0.12

= <u>1505 stk</u>

The formula can be used to work out how many strokes are required to circulate any volume, not just string or annular volumes.

How many strokes would be required to pump a 25 barrel slug if the pump output was 0.115 bbl/stk? (a slug is a volume of heavier mud than regular)

Strokes = Volume (bbl) ÷ Pump Output (bbl/stk)

= 25 ÷ 0.115

= <u>217 stk</u>

Having calculated how many strokes it will take to circulate a given volume of mud the next thing you can do is work out how long this will take.

To do this you need to know how fast you are pumping, in strokes per minute (spm), then simply divide the total strokes by the spm to get the time:

Time (min) = Strokes ÷ Pump Speed (spm)

On the previous page we worked out that there were 1505 stks needed to circulate from Surface to Bit. How long would this take at 80 spm? (nearest minute)

Time (min) = Strokes ÷ Pump Speed (spm)

= 1505 ÷ 80

= 19 min

Knowing how long a circulation will take is important for planning purposes. You may circulate bottoms up before pulling out the hole. The driller will work out how long this will take and may decide to send the roughnecks off for a meal break during the circulation so everyone is ready to start tripping once bottoms up has been circulated.

Calculate the total strokes and circulation times for the following:

a) String Volume = 127.36 bbl, Pump Output = 0.119 bbl/stk, 65 spm

b) Annular Volume = 263.33 bbl. Using the information from a) above work out total well volume strokes and circulation time.

c) How many strokes, and how long, to pump a 35 bbl slug chased by the same volume of regular mud at 45 spm using the pump above?

d) String Volume = 199.54 bbl, Annular Volume = 337.29 bbl,
Pump Liner ID = 7 $^{1}/_{2}$", Pump Stroke Length = 12", 94% efficiency
What are well strokes and circulation time at 35 spm?

ANSWERS

Strokes = Volume (bbl) ÷ Pump Output (bbl/stk)

Time (min) = Strokes ÷ Pump Speed (spm)

---

a) Strokes = 127.36 ÷ 0.119 = <u>1,070 stk</u>

Time = 1,070 ÷ 65 = <u>16 min</u>

---

b) Well Volume = 127.36 + 263.33 = <u>390.69 bbl</u>

Strokes = 390.69 ÷ 0.119 = <u>3,283 stk</u>

Time = 3,283 ÷ 65 = <u>51 min</u>

---

c) Total Volume = 35 + 35 = <u>70 bbl</u>

Strokes = 70 ÷ 0.119 = <u>588 stk</u>

Time = 588 ÷ 45 = <u>13 min</u>

d) You first need to work out the pump output in bbl/stk at the given efficiency:

$$\text{Pump Output (bbl/stk)} = d^2 \text{ (in)} \div 1029.4 \times \text{stroke length (ft)} \times 3$$

$$= 7.5^2 \div 1029.4 \times 3$$

Remember, if the stroke length is 12" you don't need to multiply by stroke length

$$= 56.25 \div 1029.4 \times 3$$

$$= 0.1639 \text{ bbl/stk @ 100\% efficient}$$

$$= 0.1639 \times 94\% = \underline{0.154 \text{ bbl/stk}}$$

$$\text{Total Volume} = 199.54 + 337.29 = \underline{236.83 \text{ bbl}}$$

$$\text{Strokes} = 236.83 \div 0.154 = \underline{3{,}486 \text{ stk}}$$

$$\text{Time} = 3{,}486 \div 35 = \underline{100 \text{ min}}$$

ANNULAR VELOCITY

We have looked at pump output in terms of volume and described it as barrels per stroke (bbl/stk).

Pump output can be looked at in terms of flow and described as barrels per minute (bbl/min) - how much fluid is being pumped every minute. Monitoring return flow from the well is key to good well control. You should be getting the same return mud flow out of the well as you are pumping into the well.

We now have a situation where the same words are being used to describe two different units. This is where it becomes very important to look at the unit when using a formula. Remember the unit is the bit in brackets.

Pump Output (bbl/min) = Pump Output (bbl/stk) x SPM

If our pump speed is 80 spm and the pump output is 0.119 bbl/stk what is the bbl/min pump output?

Pump Output (bbl/min) = Pump Output (bbl/stk) x SPM

= 0.119 x 80

= <u>9.52 bbl/min</u>

This tells you that every minute you are pumping 9.52 barrels of mud into the hole. If you are in control of the well then you should be getting 9.52 barrels of mud back out the hole every minute.

If you are getting a greater return of mud from the hole every minute then the well may be kicking on you.

If you are getting less return flow from the well then you may be taking losses somewhere.

In both situations you would have to investigate what is happening but that’s not for this book to discuss.

Knowing how much mud you are pumping every minute will allow you to calculate how quickly the mud is travelling back up the annulus. This can be important for hole cleaning.

Annular Velocity in feet per minute (ft/min) can be calculated as follows:

Annular Velocity (ft/min) = Pump Output (bbl/min) ÷ Annular Capacity (bbl/ft)

Note: The pump output used in this formula is **barrels per minute (bbl/min)**.

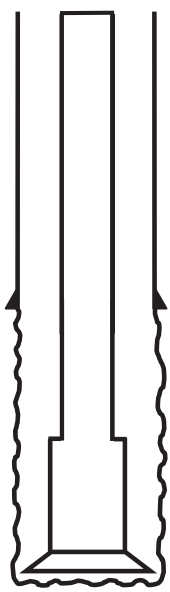
What is the Annular Velocity if the Pump Output is 9.52 bbl/min and the Annular Capacity is 0.03 bbl/ft? (nearest foot per minute)

Annular Velocity (ft/min) = Pump Output (bbl/min) ÷ Annular Capacity (bbl/ft)

= 9.52 ÷ 0.03 = 317 ft/min

As you travel up the annulus the annular capacity generally gets bigger. This means the annular velocity will slow down the closer the mud gets to surface.

Work out the annular velocity in the following hole sections if the pump speed is maintained at 120 spm:



Pump Output = 0.117 bbl/stk

a) DP - Csg: Annular Capacity = 0.0562 bbl/ft

b) DP - OH: Annular Capacity = 0.0464 bbl/ft

c) DC - OH: DC OD = 6", Bit Size = $8^1/_2$"

ANSWERS

Pump Output (bbl/min) = Pump Output (bbl/stk) x SPM

Annular Velocity (ft/min) = Pump Output (bbl/min) ÷ Annular Capacity (bbl/ft)

a) Pump Output = 0.117 x 120 = 14.04 bbl/min

Annular Velocity = 14.04 ÷ 0.0562 = 250 ft/min

---

b) Annular Velocity = 14.04 ÷ 0.0464 = 303 ft/min

---

c) You must first work out Annular Capacity:

Annular Capacity (bbl/ft) = $(D^2 - d^2) \div 1029.4$

$= (8.5^2 - 6^2) \div 1029.4$

$= (72.25 - 36) \div 1029.4$

= 0.0352 bbl/ft

Annular Velocity = 14.04 ÷ 0.0352

= 399 ft/min

Notice how the Annular Velocity decreases as you travel up the annulus. You are pumping at the same flow rate and as the annular capacity increases (the gap between the outside of the tubular and the inside of the hole or casing gets bigger) then the velocity of the mud drops.

A QUICK RECAP

The last few subjects have a strong link running through them and it is worth taking a few moments here to look at what has been covered.

The link running through them is that they are all to do with string and annular volumes. These have been described in a few different ways:

String Capacity and Volume
Annular Capacity and Volume
Pump Output
Strokes and Time
Annular Velocity

You have learned how to work out many different things from some basic well data. You will have noticed that much of the data is used across several of the calculations and that one piece of data can lead into several others.

For instance, the sizes of the hole and pipe lead to annular capacity which in turn leads to annular volume which in turn can lead to strokes, time or velocity.

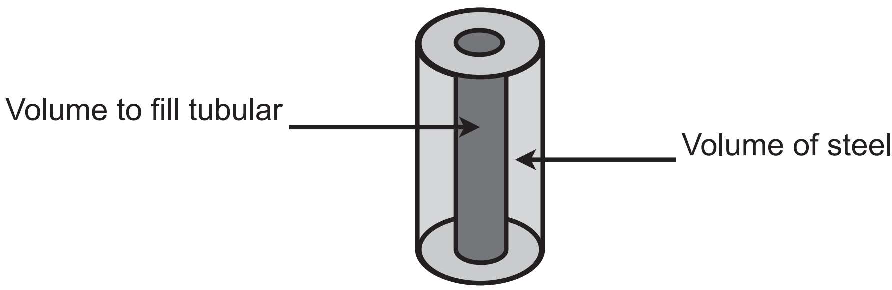
This grounding in how string and annular capacities are worked out is important in understanding the make-up of the well.

You have formulas that can help you but you are now in a position to logically work through a problem in stages even if you don't have formulas. Don't worry though, you will be given them through this book.

CAPACITIES AND DISPLACEMENTS

Let's now take a closer look at the drill string and see what it looks like. A tubular is a metal pipe with a hole through the middle of it.

There are two volumes in a tubular - the volume to fill it and the volume of the steel that actually makes up the tubular.



There are many different names used to describe these volumes. In this book the volume to fill the pipe will be called its Capacity and the volume of the steel will be called its Displacement. The unit used for both will be barrels per foot (bbl/ft).

Pipe capacity has already been talked about in great detail but why is the volume of steel called pipe displacement?

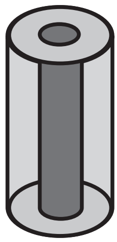
Do you remember our Greek mud logger, Archimedes? Well, he climbed into a bath full of water once and noticed that as he got in water spilled out over the side on to the floor. He then famously shouted Eureka and ran through the streets naked. Mud loggers eh - most of us would have cursed once about the mess but then carried on with our bath regardless!

The volume of water that came out the bath was equal to the volume of Archimedes - it was his displacement.

If you lower an open-ended tubular into a hole that is full of mud the pipe will fill up with mud as it is lowered. A volume of mud will be displaced out of the hole, however.

The volume of mud displaced out of the hole will be equal to the volume of the steel run into the hole - this is pipe displacement (sometimes also called steel displacement).

How can you work out Pipe Displacement? Looking at a tubular it would appear that the volume of steel could be worked out the same way you worked out Annular Capacity:



Pipe Displacement or
Annular Capacity (bbl/ft) = $(D^2 - d^2) \div 1029.4$

where Big D is the OD of the pipe and little d is its ID

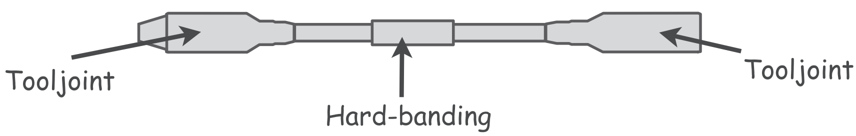
Try it for HWDP with an OD of 5" and an ID of 3".

$$\text{Pipe Displacement} = (5^2 - 3^2) \div 1029.4$$

$$= (25 - 9) \div 1029.4 = \underline{0.01554 \text{ bbl/ft}}$$

The actual displacement value for this type of HWDP is 0.01795 bbl/ft. What has caused the difference in figures?

The answer is that the actual volume of steel in a length of HWDP is more than you can calculate using the formula above due to the tooljoint and hard-banding.



So how are displacement values worked out?

Through measurement we know that one barrel of steel weighs 2,747 pounds. If we know the pounds per foot (lb/ft) weight of a tubular, we can divide that value by 2,747 to get the bbl/ft displacement.

The HWDP above weighs 49.3 lb/ft - its displacement is:

$$49.3 \div 2{,}747 = \underline{0.01795 \text{ bbl/ft}}$$

This can be done for any tubular - 2,747 is used as a conversion factor to change lb/ft into bbl/ft.

You now know how to work out string capacity, hole capacity, annular capacity and pipe displacement. There is one other term used and that is something called Closed-end Displacement.

What would happen if you were to close off the bottom end of a pipe and then run it into a hole full of mud? Would the pipe fill with mud from the hole as you run it in?

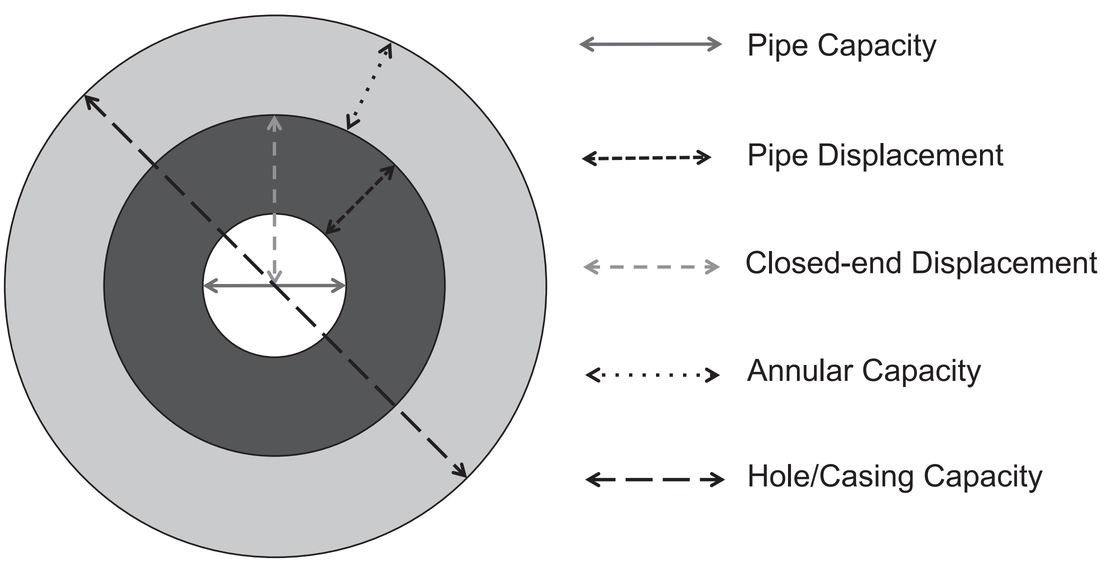
Obviously the pipe would not fill with mud from the hole because the end has been closed off and there is no way for the mud to enter the pipe from below.

What volume of mud would therefore be displaced out of the hole? The volume would be the volume of the steel (pipe displacement) **and** the volume to fill the pipe (pipe capacity). Closed-end displacement therefore is:

Closed-end Displacement (bbl/ft) = Pipe Capacity (bbl/ft) + Pipe Displacement (bbl/ft)

Closed end displacement is the volume of fluid that will be displaced when you run in the hole and the pipe cannot fill up from the hole. This will be the case if you run with a float in the string for instance.

There are five different bbl/ft capacities in a well. If you took a cross section of a well you would see the following:



CAPACITIES & DISPLACEMENTS IN THE FIELD

In the field the sizes of equipment and tools used are standard. We drill with $8^1/_2$", $12^1/_4$" & $17^1/_2$" bits across the world. Casing sizes are standard - $18^5/_8$", $13^3/_8$", $9^5/_8$" being just a few. Typical size tubulars include 5" drill pipe, 5" HWDP and drill collars ranging from $4^1/_2$" through to 12".

There are lots more than those described above but the dimensions are all known - ODs, IDs and weights in lb/ft. The capacity and displacement values are also known.

All this information is written down and can be found in data tables. These data tables are available from a number of different sources including books and on-line. There may even be some data tables in your tally book.

When you attend well control school capacities and displacement figures will also be given to you. You may, however, have to do a bit of work to get the actual number you need to answer a question!

What is the annular volume for the following section of hole?

Data: Section Length = 895 ft; Hole Capacity = 0.0702 bbl/ft;
Pipe Capacity = 0.0049 bbl/ft Pipe Displacement = 0.0332 bbl/ft

Annular Volume (bbl) = Annular Capacity (bbl/ft) x Length (ft)

You have the section length but not the annular capacity. If you subtract closed end displacement from hole capacity you will get annular capacity. Have a look at the diagram opposite if you're not sure about this.

Closed End Displacement (bbl/ft) = Pipe Capacity (bbl/ft) + Pipe Displacement (bbl/ft)

= 0.0049 + 0.0332 = 0.0381 bbl/ft

Annular Capacity = Hole Capacity - Closed End Displacement

= 0.0702 - 0.0381 = 0.0321 bbl/ft

Annular Volume = 0.0321 x 895 = 28.73 bbl

TRIP SHEET CALCULATIONS

You will know from experience that the hardest physical job on a drilling rig is when you are tripping pipe in and out of the hole. You will also know that you count the pipe in and you count the pipe out. The reason for counting the pipe is so the driller knows where the bit is in relation to the well (BOP, Shoe etc). The pipe count is also used to check that nothing untoward is happening in the well during the trip.

We have already seen that mud will be displaced out of the hole as you run pipe into the hole. This mud is displaced into the trip tank and as a result the trip tank volume will go up.

The driller will calculate how much the volume should go up by and will check this against how much the actual increase is.

The pipe displacement for a certain grade of 5" drill pipe is 0.0076 bbl/ft and the stand length is 93 ft. How much mud will one stand displace into the trip tank?

Volume (bbl) = Capacity (bbl/ft) x Length (ft)

(the formula asks for capacity - displacement is the same thing a bbl/ft number)

= 0.0076 x 93 = 0.71 bbl

In this example the trip tank volume will go up by almost 3/4 of a barrel for every stand run into the hole. This could be a little tricky to check on a stand-by-stand basis so the driller will usually monitor the displacement volume every 5 stands when tripping drill pipe.

= 0.71 x 5 = 3.55 bbl

What will the displacement per stand be for the HWDP and Drill Collars below?

HWDP Displacement - 0.0179 bbl/ft, stand length 92 ft
Drill Collar Displacement - 0.0349 bbl/ft, stand length 88 ft

HWDP: = 0.0179 x 92 = 1.65 bbl
DC: = 0.0349 x 88 = 3.07 bbl

Displacement volume is usually monitored every stand for HWDP & Drill Collars due to the much larger volumes displaced per stand.

The driller will work out the calculated displacement volumes for the drill pipe, HWDP & Drill Collars run into the hole and will record them on a trip sheet. During the trip the driller will then monitor the actual volume of mud displaced into the trip tank - it should be the same as he has calculated. If there are any major differences, then those will be investigated as there could be a problem down hole, such as a kick or losses.

The actual volume of mud the trip tank holds will depend on the type of rig you are working on, but will be relatively small compared to your main mud system. As mud is displaced out of the hole the trip tank is going to fill up. At some point it will be almost full and you will need to transfer some to the active system. The actual amount transferred will need to be recorded on the trip sheet so the count can continue accurately.

Trip sheets vary from company to company but will look a bit like this:

Displacement Figures	Drill Pipe 0.0076 bbl/ft		HWDP 0.0179 bbl/ft		Drill Collars 0.0349 bbl/ft		
Stand No	**Length Run/~~Pulled~~**	**Total Length**	**Calculated Displacement**	**Trip Tank Volume**	**Actual Displacement**	**Total Displacement**	**Difference**
0	0	0	0	5	0	0	-
5	465	465	3.5	8.5	3.5	3.5	0
10	465	930	3.5	12	3.5	7	0
15	460	1,390	3.5	15.5	3.5	10.5	0
20	463	1,853	3.5	19	3.5	14	0

In this example note how the length per 5 stands and the total (or accumulated) length run have both been recorded. The total length is worked out by adding the length just run to the previous total.

Also note that the actual displacement per 5 stands and the total displacement have both been recorded. The actual displacement has been worked out by subtracting the previous trip tank reading from the current one. Displacement is to one decimal place - as accurate as you will get on a trip tank.

Any difference between calculated and actual is noted and should be investigated.

If you had a 20 barrel trip tank you would now need to think about transferring some mud to the active pit. You would have to accurately measure how much you transferred and make a note of this on the sheet.

Displacement Figures	Drill Pipe 0.0076 bbl/ft		HWDP 0.0179 bbl/ft		Drill Collars 0.0349 bbl/ft		
Stand No	**Length Run/~~Pulled~~**	**Total Length**	**Calculated Displacement**	**Trip Tank Volume**	**Actual Displacement**	**Total Displacement**	**Difference**
0	0	0	0	5	0	0	-
5	465	465	3.5	8.5	3.5	3.5	0
10	465	930	3.5	12	3.5	7	0
15	460	1,390	3.5	15.5	3.5	10.5	0
20	463	1,853	3.5	19	3.5	14	0
15 bbl transferred to Active				4	-	14	0
25	468	2,321	3.6	7.6	3.6	17.6	0

Complete the trip sheet opposite to run the following drill string in the hole. Assume that all actual displacements are as calculated. The trip tank holds 20 barrels. The trip tank start volume is 4 barrels. You should transfer mud out the trip tank if you cannot displace the next amount into it. Transfer 15 bbl out each time.

Drill pipe displacement should be monitored every 5 stands. HWDP and drill collar displacement should be monitored every stand.

Drill Collars: Stand 1 = 90ft; Stand 2 = 92ft; Stand 3 = 88ft

HWDP: Stand 1 = 94ft; Stand 2 = 90ft; Stand 3 = 91ft

Drill pipe Stands: 1-5 = 465ft; 6-10 = 466ft; 11-15 = 460ft; 16-20 = 462ft

21-25 = 467ft; 26-30 = 470ft; 31-35 = 466ft; 36-40 = 461ft

41-45 = 462ft; 46-50 = 452ft; 51-55 = 462ft;

Mud Loggers remember, drill collars go in first, then HWDP then drill pipe!

Displacement Figures	Drill Pipe 0.0076 bbl/ft		HWDP 0.0179 bbl/ft		Drill Collars 0.0349 bbl/ft		
Stand No	Length Run/~~Pulled~~	Total Length	Calculated Displacement	Trip Tank Volume	Actual Displacement	Total Displacement	Difference

ANSWERS

Displacement Figures	Drill Pipe 0.0076 bbl/ft		HWDP 0.0179 bbl/ft		Drill Collars 0.0349 bbl/ft		
Stand No	**Length Run/~~Pulled~~**	**Total Length**	**Calculated Displacement**	**Trip Tank Volume**	**Actual Displacement**	**Total Displacement**	**Difference**
0	-	-	-	4	-	-	-
DC1	90	90	3.1	7.1	3.1	3.1	0
DC2	92	182	3.2	10.3	3.2	6.3	0
DC3	88	270	3.1	13.4	3.1	9.4	0
HWDP1	94	364	1.7	15.1	1.7	11.1	0
HWDP2	90	454	1.6	16.7	1.6	12.7	0
HWDP3	91	545	1.6	18.3	1.6	14.3	0
15 bbl transferred to active				3.3	-	14.3	0
5	465	1,010	3.5	6.8	3.5	17.8	0
10	466	1,476	3.5	10.3	3.5	21.3	0
15	460	1,936	3.5	13.8	3.5	24.8	0
20	462	2,398	3.5	17.3	3.5	28.3	0
15 bbl transferred to active				2.3	-	28.3	0
25	467	2,865	3.5	5.8	3.5	31.8	0
30	470	3,335	3.6	9.4	3.6	35.4	0
35	466	3,801	3.5	12.9	3.5	38.9	0
40	461	4,262	3.5	16.4	3.5	42.4	0
45	462	4,724	3.5	19.9	3.5	45.9	0
15 bbl transferred to active				4.9	-	45.9	0
50	452	5,176	3.4	8.3	3.4	49.3	0
55	462	5,638	3.5	11.8	3.5	52.8	0

As you trip into the hole mud is displaced out and must be monitored to ensure the correct amount is being displaced.

As you pull pipe out of the hole the level of mud will drop as you remove the pipe. One of the golden rules of well control is to ensure that the hole is kept full at all times. This is done by circulating the trip tank across the top of the hole. Mud is circulated from the trip tank, across the top of the hole and back into the trip tank thus ensuring the hole is always full.

As you pull pipe out the hole you remove a volume from the hole and this will be replaced by mud from the trip tank. This means the trip tank volume will go down. The driller will monitor the drop in the trip tank level to ensure it is as calculated. Every now and again the driller will have to transfer mud into the trip tank as it falls towards empty.

Complete the trip sheet below for a trip out the hole. Transfer 15 bbl in when the trip tank volume falls below 5 bbl. Monitor as before - trip in order shown.

DP 1-5 = 465ft; DP 6-10 = 466ft; HWDP1 = 94ft; HWDP2 = 90ft; DC1 = 90ft; DC2 = 88ft; DC3 = 89ft

Displacement Figures	Drill Pipe 0.0076 bbl/ft		HWDP 0.0179 bbl/ft		Drill Collars 0.0349 bbl/ft		
Stand No	Length ~~Run~~/Pulled	Total Length	Calculated Displacement	Trip Tank Volume	Actual Displacement	Total Displacement	Difference
-	-	-	-	10	-	-	-

ANSWERS

Displacement Figures	Drill Pipe 0.0076 bbl/ft		HWDP 0.0179 bbl/ft		Drill Collars 0.0349 bbl/ft		
Stand No	**Length ~~Run~~/Pulled**	**Total Length**	**Calculated Displacement**	**Trip Tank Volume**	**Actual Displacement**	**Total Displacement**	**Difference**
-	-	-	-	10	-	-	-
DP5	465	465	3.5	6.5	3.5	3.5	0
DP10	466	931	3.5	3	3.5	7	0
15 bbl transferred from active				18	-	7	0
HWDP1	94	1,025	1.7	16.3	1.7	8.7	0
HWDP2	90	1,115	1.6	14.7	1.6	10.3	0
DC1	90	1,205	3.1	11.6	3.1	13.4	0
DC2	88	1,293	3.1	8.5	3.1	16.5	0
DC3	89	1,382	3.1	5.4	3.1	19.6	0

Accurate trip monitoring both in and out of the hole is one of the key responsibilities of the driller. The calculations involved are not difficult to do but accuracy and neatness are important.

When you get back to the rig have a look at some completed trip sheets. Get one of your supervisors to explain how it works on your rig. Find out what information is different from the example you have used here.

If you have never filled one in on the rig ask for a blank one and complete it either for a real trip or just make some figures up. Get one of your supervisors to check it over.

KILL SHEET VOLUME CALCULATIONS

Maintaining accurate trip monitoring is important in well control. If the displacement or hole fill are wrong on a trip then you could have a well kick situation on your hands. A kick is when formation fluid (gas in many cases) enters the well bore. We will look at well control in Book Four of this series.

However the kick got in, it will need to be circulated out. In order to circulate the kick out you need to know what your string and annular volumes are. This could be done as covered earlier, but on the rig is usually done using a kick sheet.

Your company will either have its own kick sheet or it will use one of the many standard kick sheets that are available, such as those provided by IADC or IWCF.

The kick sheet is a simple form that helps you work out the string and annular volumes for the well. The number of strokes required to circulate various sections of the well are also usually worked out on the kick sheet. It is also used to calculate some pressure calculations but these will be dealt with in Book Four.

A lot of companies require that a kill sheet is partially prepared every shift and is maintained ready in the event of a kick situation.

While kick sheets may look different and be laid out in different ways the key volume information on them all will be the same. You will always calculate:

Drill Pipe volume
HWDP volume } drill string volume
Drill Collar volume

DC-OH annular volume
open-hole volume { DP-OH annular volume } annular volume
DP-Csg annular volume

Pump output will be recorded somewhere and you can then calculate the required strokes for each section. If you know the kill rate you can calculate how long it will take. All kick sheets will have these calculations on them somewhere. We will only look at a surface kick sheet in this book.

When you attend well control school you will have to complete a kick sheet as part of the final written exam and in many cases you will also have to complete one for the practical.

The kick sheet is nothing to be scared about, particularly if you have worked honestly through this book as far as here.

You will be given some information and a blank kick sheet to complete. To work out the volume calculations you need only find two key pieces of information for each section:

> the length of the section and the capacity of the tubular or annulus

Once you have this information simply put the figures into the appropriate place on the kick sheet then go ahead and do the calculations.

Usually there will be a little bit of problem solving to do first, however. You are not normally given drill pipe length for instance but you will be given the measured depth of the well and the lengths of the HWDP and drill collars.

The same goes for the annular lengths - you will have to work them out from the information given. Some kick sheets have a well diagram to help with this. If there isn't one then draw one on a sheet of paper.

Complete the volume calculations on the kick sheet opposite:

Well Measured Depth = 13,783 ft
Drill Pipe Capacity = 0.01776 bbl/ft
HWDP Capacity = 0.0087 bbl/ft; Length = 728 ft
Drill Collars Capacity = 0.0061 bbl/ft; Length = 534 ft
Shoe Measured Depth = 8,776 ft;
DP-Csg Annular Capacity = 0.0502 bbl/ft
DP-OH Annular Capacity = 0.0459 bbl/ft
DC-OH Annular Capacity = 0.0322 bbl/ft
Pump Output = 0.117 bbl/stk
Pump Kill Rate will be 35 spm

Pump Output	Pump Kill Rate
bbl/stk	spm

Strokes = Volume ÷ Pump Output

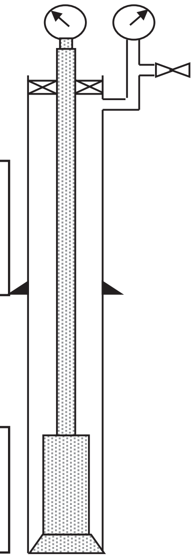
Time = Strokes ÷ Pump Kill Rate

Casing Shoe Measured Depth

feet

Well Measured Depth

feet



Volume Data	Length (feet) x	Capacity (bbl/ft) =	Volume (bbl)	Strokes	Time (min)
Drill Pipe					
HWDP					
Drill Collars					
Total Drill String Volume = DP + HWDP + DC					
Drill Collars - Open-Hole					
Drill Pipe - Open-Hole					
Total Open-Hole Volume = DC-OH + DP-OH					
Drill Pipe - Cased Hole					
Total Annulus Volume = DC-OH + DP-OH + DP-Csg					
Total Well Volume = Total String + Total Annulus					

ANSWERS

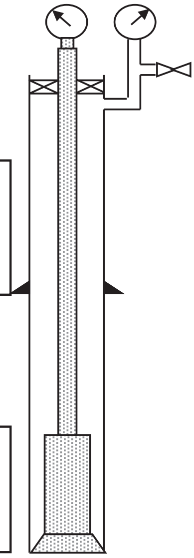
Pump Output	Pump Kill Rate
0.117 bbl/stk	35 spm

Strokes = Volume ÷ Pump Output

Time = Strokes ÷ Pump Kill Rate

Casing Shoe Measured Depth

8,776 feet



Well Measured Depth

13,783 feet

Volume Data	Length (feet)	x Capacity (bbl/ft)	= Volume (bbl)	Strokes	Time (min)
Drill Pipe	12,521	0.01776	222.37		
HWDP	728	0.0087	6.33		
Drill Collars	534	0.0061	3.26		
Total Drill String Volume = DP + HWDP + DC			231.96	1983	57
Drill Collars - Open-Hole	534	0.0322	17.19		
Drill Pipe - Open-Hole	4,473	0.0459	205.31		
Total Open-Hole Volume = DC-OH + DP-OH			222.5	1902	54
Drill Pipe - Cased Hole	8,776	0.0502	440.56		
Total Annulus Volume = DC-OH + DP-OH + DP-Csg			663.06	5,667	162
Total Well Volume = Total String + Total Annulus			895.02	7,650	219

Try to get a hold of a copy of a different type of kick sheet - ideally the one in use on your rig - and complete the volume calculations using the same data. You have the correct answers to check against.

See where the differences are but also see that the main calculations are the same on both types of kick sheet. Knowing this means you can change quickly from one kick sheet to another - all you need to do is find where the calculations are on the new sheet.

Well, it's almost test time again. This chapter has been about volumes and some of the associated calculations around volumes. Subjects have included:

Pit Volume
Hole Volume
String Capacity and Volume
Annular Capacity and Volume
Pump Output
Strokes and Time
Annular Velocity
Trip Sheet Calculations
Kill Sheet Volume Calculations

Many of these skills will now be tested. If you're unsure about any of the topics have a look back now before you start the test. All formulas needed will be given one way or another so there's no need to memorise them.

Before you start get everything ready - calculator, pen & paper and a clear space on your desk. Take a quick break then make a start. Fully worked-out answers follow the test but finish the test before looking at them.

Remember, write everything down and take your time - there is no hurry or time limit.

CHAPTER TEST

Using the data and formulas below complete the following:

1) Fill in the kick sheet opposite.

2) What is the annular velocity at kill rate in the DC-OH, DP-OH and DP-Csg annular sections?

3) How much mud will every 92ft stand of drill pipe displace into the trip tank.

4) How many barrels of mud does the trip tank hold?

Round answers as follows:

Capacities (bbl/ft) - 5 decimal places; Volume (bbl) 2 decimal places
Pump Output (bbl/stk) - 3 decimal places Strokes - whole strokes
Pump Output (bbl/min) - 2 decimal places Time (min) - whole minutes
Annular Velocity (ft/min) - whole ft/min

Well Measured Depth = 9,224 ft
Drill Pipe ID = 4.408"; Displacement = 0.0059 bbl/ft,
HWDP ID = $3^1/_4$"; Length = 566 ft
Drill Collar OD = $8^3/_4$"; ID = 2.8125"; Length = 442 ft
Shoe Measured Depth = 5,445 ft;
DP-Csg Annular Capacity = 0.1304 bbl/ft
DP-OH Annular Capacity = 0.1215 bbl/ft
Open Hole ID = $12^1/_4$"
Triplex Pump with 12" stroke, ID of $6^1/_4$" & 96% efficiency
Pump Kill Rate will be 30 spm
Trip Tank Dimensions: L = 4ft; W = 4ft; D = 10ft

String Capacity (bbl/ft) = d^2 (in) ÷ 1029.4
Annular Capacity (bbl/ft) = $(D^2 - d^2)$ ÷ 1029.4
Pump Output (bbl/stk) = d^2 (in) ÷ 1029.4 x stroke length (ft) x 3
Pump Output (bbl/min) = Pump Output (bbl/stk) x SPM
Annular Velocity (ft/min) = Pump Output (bbl/min) ÷ Annular Capacity (bbl/ft)
Volume (bbl) = Capacity (bbl/ft) x Length (ft)
Square-sided Tank Volume (bbl) = Length (ft) x Width (ft) x Depth (ft) x 0.1781

Pump Output	Pump Kill Rate
bbl/stk	spm

Strokes = Volume ÷ Pump Output

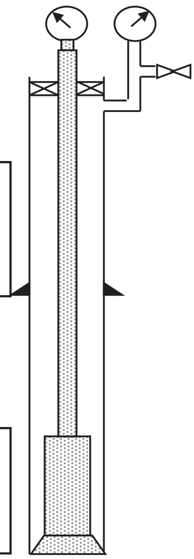
Time = Strokes ÷ Pump Kill Rate

Casing Shoe Measured Depth

feet

Well Measured Depth

feet



Volume Data	Length (feet)	x Capacity (bbl/ft)	= Volume (bbl)	Strokes	Time (min)
Drill Pipe					
HWDP					
Drill Collars					
Total Drill String Volume = DP + HWDP + DC					
Drill Collars - Open-Hole					
Drill Pipe - Open-Hole					
Total Open-Hole Volume = DC-OH + DP-OH					
Drill Pipe - Cased Hole					
Total Annulus Volume = DC-OH + DP-OH + DP-Csg					
Total Well Volume = Total String + Total Annulus					

ANSWERS

1) Before the kick sheet can be completed you will have to work out some of the data that goes on it. The information you need to work out is:

Pump Output
The capacities of all the tubulars
The drill collar to open hole annular capacity

Pump Output (bbl/stk) = d^2 (in) ÷ 1029.4 x stroke length (ft) x 3 x 96%

= 6.25^2 ÷ 1029.4 x 3 x 96% = <u>0.109 bbl/stk</u>

Remember when the stroke length is 12 inches, or 1 foot, you do not need to multiply by stroke length

---

String Capacity (bbl/ft) = d^2 (in) ÷ 1029.4

Drill pipe capacity = 4.408^2 ÷ 1029.4 = <u>0.01888 bbl/ft</u>

HWDP capacity = 3.25^2 ÷ 1029.4 = <u>0.01026 bbl/ft</u>

Drill collar capacity = 2.8125^2 ÷ 1029.4 = <u>0.00768 bbl/ft</u>

Annular Capacity (bbl/ft) = (D^2 - d^2) ÷ 1029.4

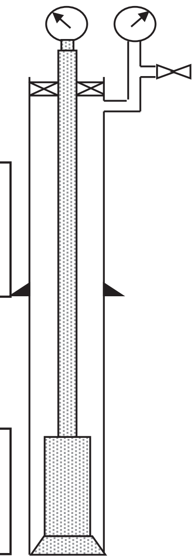
= (12.25^2 - 8.75^2) ÷ 1029.4 = <u>0.0714 bbl/ft</u>

Pump Output	Pump Kill Rate
0.109 bbl/stk	30 spm

Strokes = Volume ÷ Pump Output

Time = Strokes ÷ Pump Kill Rate

Casing Shoe Measured Depth: 5,445 feet



Well Measured Depth: 9,224 feet

Volume Data	Length (feet)	x Capacity (bbl/ft)	= Volume (bbl)	Strokes	Time (min)
Drill Pipe	8,216	0.01888	155.12		
HWDP	566	0.01026	5.81		
Drill Collars	442	0.00768	3.39		
Total Drill String Volume = DP + HWDP + DC			164.32	1,507	50
Drill Collars - Open-Hole	442	0.0714	31.56		
Drill Pipe - Open-Hole	3,337	0.1215	405.45		
Total Open-Hole Volume = DC-OH + DP-OH			437.01	4,009	134
Drill Pipe - Cased Hole	5,445	0.1304	710.03		
Total Annulus Volume = DC-OH + DP-OH + DP-Csg			1,147.04	10,523	351
Total Well Volume = Total String + Total Annulus			1,311.36	12,031	401

2) Annular Velocity (ft/min) = Pump Output (bbl/min) ÷ Annular Capacity (bbl/ft)

Pump Output (bbl/min)= Pump Output (bbl/stk) x SPM

= 0.109 x 30 = 3.27 bbl/min

Annular Velocity DC-OH = 3.27 ÷ 0.0714 = 46 ft/min

Annular Velocity DP-OH = 3.27 ÷ 0.1215 = 27 ft/min

Annular Velocity DP-Csg = 3.27 ÷ 0.1304 = 25 ft/min

---

3) Volume (bbl) = Capacity (bbl/ft) x Length (ft)

= 0.0059 x 92 = 0.54 bbl

---

4) Square-sided Tank Volume (bbl) = Length (ft) x Width (ft) x Depth (ft) x 0.1781

= 4 x 4 x 10 x 0.1781

= 28.5 bbl

FINAL SCORE

Use the marking table below to score how well you did in the chapter test.

Question	Answer	Correct or Incorrect	Value	Your Score
1 pump output	0.109 bbl/stk		3	
1 DP capacity	0.01888 bbl/ft		3	
1 HWDP capacity	0.01026 bbl/ft		3	
1 DC capacity	0.00768 bbl/ft		3	
1 DC-OH Ann Cap	0.0714 bbl/ft		3	
1 kill sheet drill string stks	1,507 stks		3	
1 kill sheet open hole stks	4,009 stks		3	
1 kill sheet total well stks	12,031 stks		3	
2 DC-OH Annular velocity	46 ft/min		3	
2 DP-OH Annular velocity	27 ft/min		3	
2 DP-Csg Annular velocity	25 ft/min		3	
3	0.54 bbl		3	
4	28.5 bbl		3	
Total Score Available = 39 Points		Your Total Score =		

Your Score = __________ ÷ 39 x 100 = [%]

Round to the nearest whole percentage. If you scored 70% or above then you passed.

LAST WORD

So you made it to the end of the second chapter - well done again.

You are now halfway through the book, which is even better news.

This chapter has taken the calculation skills you learned in the first section and shown you how to apply them for a number of different volume calculations.

There are other volume calculations that have not been covered in this chapter, such as those needed when running casing for instance. Now you understand how volumes work you will pick these up pretty quickly when you need to.

The next chapter will introduce you to pressure calculations.

There will be some new terms but there will be some familiar ones also.

Have a break before starting the next chapter - don't wait too long though.

No mud loggers were hurt in the making of this chapter.

NOTES

CHAPTER 3
PRESSURE CALCULATIONS

This chapter introduces you to pressure and many of the pressure related calculations. Once again the build up is slow and easy, establishing one concept before moving on to the next. Topics include:

- Pressure gradient
- Hydrostatic pressure
- Circulating pressures
- Change of pump speed
- Change of mud weight
- Formation strength
- Tripping pressure calculations

Once again to finish off the chapter there is a chapter test for you to try.

D. Cormack, *An Introduction to Well Control Calculations for Drilling Operations*, DOI 10.1007/978-3-319-63190-5_3

DON'T PANIC

Welcome to the third chapter in this Introduction to Well Control Calculations for Drilling Operations.

You are now over halfway through and have mastered calculations. This chapter will just introduce some new topics.

Last time round you looked at volume calculations in a well. You are able to calculate how much mud it takes to fill the string and annulus. This time we will look at the pressure that mud exerts in the well.

This chapter is laid out exactly as the first two were. There are a number of lessons which make up a subject. Each lesson will be no more than two pages long which means you always have a complete lesson to view. You never need to turn the page to complete a learning point.

There are worked examples - go through them using your own calculator to see how they work. There are a number of calculations for you to try yourself. Do them all.

Fully worked-out answers are given for each question - make sure you try the questions before looking at the answers.

When working out calculations remember to write them down, ensuring everything is clearly written and identified. Write down all the stages of a calculation, including the final answer, with its correct unit.

By the time you have completed this chapter, and done so honestly, you will be ready for the fourth which will look at both volume and pressure calculations in a well control situation. You will only be able to do this, though, if you:

Take your time. **Do not skip anything.** **Read every word.**

Do every calculation.

A QUICK REFRESHER

Before you start on the pressure calculations it is worth quickly refreshing what you learned in chapter two. The subjects covered included:

Pit Volume
Hole Volume
String Capacity and Volume
Annular Capacity and Volume
Pump Output
Strokes and Time
Annular Velocity
Trip Sheet Calculations
Kill Sheet Volume Calculations

Time to get that calculator finger going again. Here is a question to get you warmed up.

How long will it take to circulate from surface to bit?

String Capacity (bbl/ft) = d^2 (in) ÷ 1029.4

Pump Output (bbl/stk) = d^2 (in) ÷ 1029.4 x stroke length (ft) x 3

Strokes = Volume (bbl) ÷ Pump Output (bbl/stk)

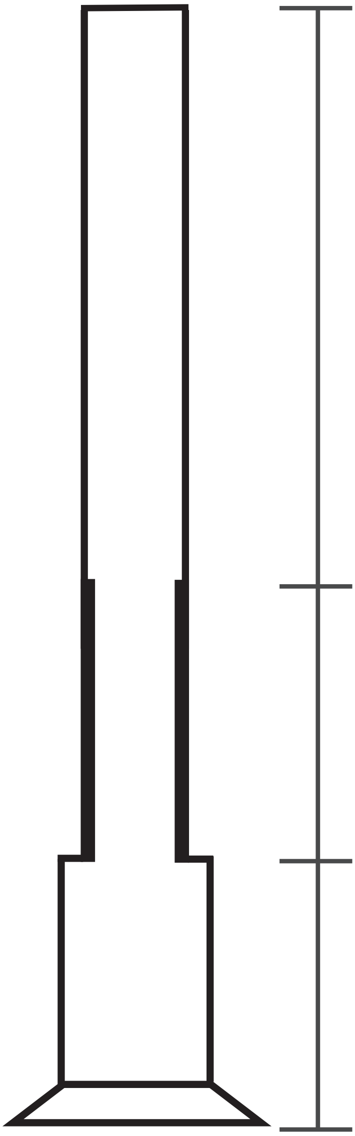
Time (min) = Strokes ÷ Pump Speed (spm)

Well Measured Depth = 8,745 ft
Drill Pipe ID = 4.276"; Displacement = 0.0059 bbl/ft
HWDP ID = $3^1/_4$"; Length = 612 ft
Drill Collar OD = $8^3/_4$"; ID = 2.75"; Length = 442 ft
Triplex Pump with 12" stroke, ID of 6" & 98% efficiency
Pump speed = 65 spm

Round capacities to 4 decimal places, output to 3 and volume to 2.

ANSWERS

DRILL STRING VOLUMES



Drill Pipe

Length = 8,745 - 612 - 442 = 7,691 ft

Capacity = $4.276^2 \div 1029.4 = 0.0178$ bbl/ft

Volume = $0.0178 \times 7{,}691 =$ 136.9 bbl

HWDP

Length = 612 ft

Capacity = $3.25^2 \div 1029.4 = 0.0103$ bbl/ft

Volume = $0.0103 \times 612 =$ 6.24 bbl

Drill Collars

Length = 442 ft

Capacity = $2.75^2 \div 1029.4 = 0.0073$ bbl/ft

Volume = $0.0073 \times 442 =$ 3.23 bbl

Total Drill String Volume = 136.9 + 6.24 + 3.23 = 146.37 bbl

Pump Output (bbl/stk) = d^2 (in) ÷ 1029.4 x stroke length (ft) x 3

= 6^2 ÷ 1029.4 x 3

= 0.105 bbl/stk

= 0.105 x 98%

= <u>0.103 bbl/stk</u>

Strokes = Volume (bbl) ÷ Pump Output (bbl/stk)

= 146.37 ÷ 0.103

= <u>1,421 stk</u>

Time (min) = Strokes ÷ Pump Speed (spm)

= 1,421 ÷ 65

= <u>22 min</u>

No real problems with these hopefully.

Remember to write things down before picking up the calculator. This will allow you to plan the calculation before jumping into it.

Work out calculations in stages to help keep them clear. Underline key answers to highlight them on the page and draw a line underneath completed calculations.

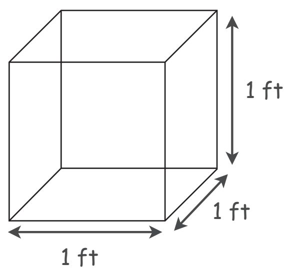
Take your time - there is no hurry.

PRESSURE GRADIENT

And so to pressure. Pressure is very important in drilling. You need to have enough pressure in the well to prevent it from flowing before you want it to. On the other hand, you need to ensure you do not apply too much pressure to the well, which may cause the formation to breakdown.

Pressure is how much force is put on the surface of one thing by something else. In this chapter we will mainly be looking at how much pressure drilling mud exerts on the bottom of a well. In field units pressure is expressed in pounds per square inch (psi).

Before we look at a well let's take a look at how pressure is measured.

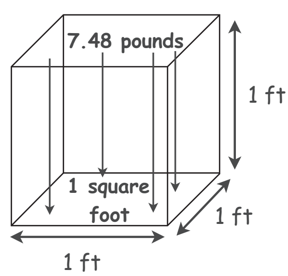


If we take a cube that measures 1 foot on all sides it will have a volume of 1 cubic foot:

$1ft \times 1ft \times 1ft = 1\ ft^3$

There are 7.48 gallons in 1 ft^3. We know this from measurement.

If this cube was filled with mud that weighed 1 pound per gallon (1 ppg) then we would have 7.48 pounds acting on the bottom of the cube.



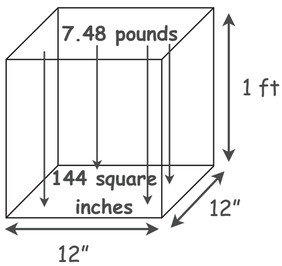
The area on the bottom of the cube is 1 square foot:

$1ft \times 1ft = 1\ ft^2$

This means there are 7.48 pounds acting down per square foot.

In field units we express pressure as pounds per square inch (psi) not pounds per square foot.

There are 144 square inches in one square foot - 12" x 12" = 144 in^2



The pressure acting on the bottom of this cube is:

7.48 pounds per 144 square inches

which divides out to give:

7.48 ÷ 144 = 0.05194 psi

This important number in well control is rounded to: 0.052.

0.052 is the pressure exerted in psi by one foot of mud that weighs 1 ppg.

It is the pressure gradient of 1 ppg mud.

Pressure gradient is how much the pressure will change by, per foot, and is expressed as psi per foot (psi/ft).

You have seen that 1 foot of 1 ppg mud exerts 0.052 psi of pressure. You can therefore say that the pressure gradient of 1 ppg mud is:

1 x 0.052 = 0.052 psi/ft

0.052 is used as a constant to work out the pressure gradients for fluids of different ppg mud weights using the formula:

Pressure Gradient (psi/ft) = Mud Weight (ppg) x 0.052

Pressure gradient is how much the pressure will change by, per foot, depending on the mud weight.

The pressure gradient of 1ppg mud is:

Pressure Gradient (psi/ft) = Mud Weight (ppg) x 0.052

= 1 x 0.052

= 0.052 psi/ft

The formula can be used to convert any ppg mud weight to a pressure gradient.

If the mud weight was 9 ppg, what would the pressure gradient be?

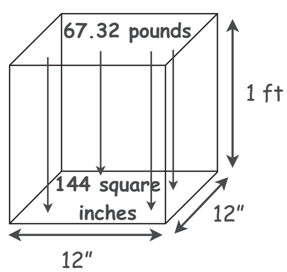
Pressure Gradient (psi/ft) = Mud Weight (ppg) x 0.052

= 9 x 0.052

= 0.468 psi/ft

This means that every foot of 9 ppg mud will exert 0.468 psi of pressure on the bottom of a well. Let's check that.

If we have one cubic foot (or 7.48 gallons) of 9 ppg mud then it will weigh:



9 ppg x 7.48 gal = 67.32 pounds

67.32 pounds acting on 144 square inches is:

67.32 ÷ 144 = 0.4675 psi

which we could round to:

0.468 psi/ft

To convert a mud weight in ppg to a pressure gradient in psi/ft you multiply the mud weight by the constant 0.052 as shown by the formula:

Pressure Gradient (psi/ft) = Mud Weight (ppg) x 0.052

How would you convert a pressure gradient in psi/ft to a mud weight in ppg?

In chapter one you learned that you rearrange a formula by moving things from one side of the equals sign to the other. When you move something from one side to the other you must do the opposite calculation with it.

Here the constant 0.052 has to be moved across. You must divide by it on the new side. So the formula changes:

Pressure Gradient (psi/ft) = Mud Weight (ppg) x 0.052

Pressure Gradient (psi/ft) ÷ 0.052 = Mud Weight (ppg) OR

Mud Weight (ppg) = Pressure Gradient (psi/ft) ÷ 0.052

Mud weight and pressure gradient are interchangeable - if you have one, you can work out the other, simply either multiply or divide by 0.052

Work out the following:

1) What is the pressure gradient of 11.5 ppg mud?

2) What is the weight in ppg of mud with a gradient of 0.7 psi/ft?

3) What is the pressure gradient of 15.3 ppg mud?

4) What is the weight in ppg of mud with a gradient of 0.465 psi/ft?

Round mud weights to two decimal places and pressure gradients to four.

ANSWERS

1) Pressure Gradient (psi/ft) = Mud Weight (ppg) x 0.052

= 11.5 x 0.052 = 0.598 psi/ft

---

2) Mud Weight (ppg) = Pressure Gradient (psi/ft) ÷ 0.052

= 0.7 ÷ 0.052 = 13.46 ppg

---

3) Pressure Gradient (psi/ft) = Mud Weight (ppg) x 0.052

= 15.3 x 0.052 = 0.7956 psi/ft

---

4) Mud Weight (ppg) = Pressure Gradient (psi/ft) ÷ 0.052

= 0.465 ÷ 0.052 = 8.94 ppg

It is important to know the relationship between mud weight and pressure gradient. You should be able to convert one to the other without having to look at a formula.

Any time you see a ppg mud weight, you multiply by 0.052 to get a psi/ft pressure gradient.

Any time you see a psi/ft pressure gradient, you divide it by 0.052 to get a ppg mud weight.

Different units for mud weight & pressure gradient will use different constants. In this book we will only use field units - ppg, psi/ft and 0.052.

HYDROSTATIC PRESSURE

If you know the pressure gradient of a mud, and you know how many feet of mud you have, you will be able to work out the total pressure the mud will exert on the bottom.

Mud that weighs 11.5 ppg has a pressure gradient of:

11.5 x 0.052 = 0.598 psi/ft

Each foot of this mud exerts 0.598 psi of pressure.

If there were two feet of this mud it would exert:

0.598 psi per foot x 2 feet = 1.196 psi

If there were 9,500 feet of this mud it would exert:

0.598 psi per foot x 9,500 feet = 5,681 psi

This pressure is known as Hydrostatic Pressure. It is the pressure the column of fluid (hydro) exerts on the bottom of the well when it is not moving (static).

You can work out hydrostatic pressure as follows:

Hydrostatic Pressure (psi) = Pressure Gradient (psi/ft) x Depth (ft)

What hydrostatic pressure (nearest psi) will the following columns of mud exert?

1) Pressure Gradient = 0.465 psi/ft; Depth = 12,000 ft

2) Pressure Gradient = 0.759 psi/ft; Depth = 14,850 ft

3) Pressure Gradient = 0.55 psi/ft; Depth = 9,720 ft

4) Pressure Gradient = 0.6812 psi/ft; Depth = 11,640 ft

ANSWERS

Hydrostatic Pressure (psi) = Pressure Gradient (psi/ft) x Depth (ft)

1) 0.465 x 12,000 = 5,580 psi

2) 0.759 x 14,850 = 11,271 psi

3) 0.55 x 9,720 = 5,346 psi

4) 0.6812 x 11,641 = 7,930 psi

As you have seen hydrostatic pressure can be worked out using the formula:

Hydrostatic Pressure (psi) = Pressure Gradient (psi/ft) x Depth (ft)

You also have a formula for pressure gradient:

Pressure Gradient (psi/ft) = Mud Weight (ppg) x 0.052

You could use mud weight and 0.052 in the hydrostatic pressure formula, in place of pressure gradient, to give you another formula for hydrostatic pressure:

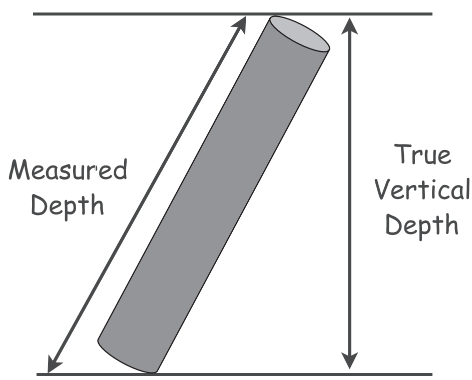
Hydrostatic Pressure (psi) = Mud Weight (ppg) x 0.052 x Depth (ft)

Hydrostatic pressure is exerted by a column of mud in a well. If you change the mud weight then hydrostatic pressure will change. That makes sense. If you have a heavier mud then it is going to exert more pressure. If you have a lighter mud then it is going to exert less pressure.

If you change the depth, or the length of the mud column, then the pressure will also change. If you have a greater depth of mud then you will have a greater pressure. If you have less depth you will have less pressure.

But what is meant by depth?

You could have two different depths in a well. There is measured depth which is how long the well physically is from surface to bit. There is also true vertical depth which is how deep the well is in a straight vertical line from surface to bit.



Pressure is a function of true vertical depth.

Measured depth is used to work out volumes as you saw in section two.

True vertical depth (TVD) is used for all pressure calculations.

Pressure is not affected by how long the well is - measured depth - it is only affected by how deep it is from surface - true vertical depth.

This gives us a final version of the hydrostatic pressure formula which is:

$$\text{Hydrostatic Pressure (psi)} = \text{Mud Weight (ppg)} \times 0.052 \times \text{TVD (ft)}$$

This formula underpins many other formulas that deal with pressure in the well.

Hydrostatic pressure is a function of mud weight and true vertical depth, and is expressed using the formula:

Hydrostatic Pressure (psi) = Mud Weight (ppg) x 0.052 x TVD (ft)

What is the hydrostatic pressure at the bottom of a well that has a TVD of 10,000 ft and is full of 10 ppg mud?

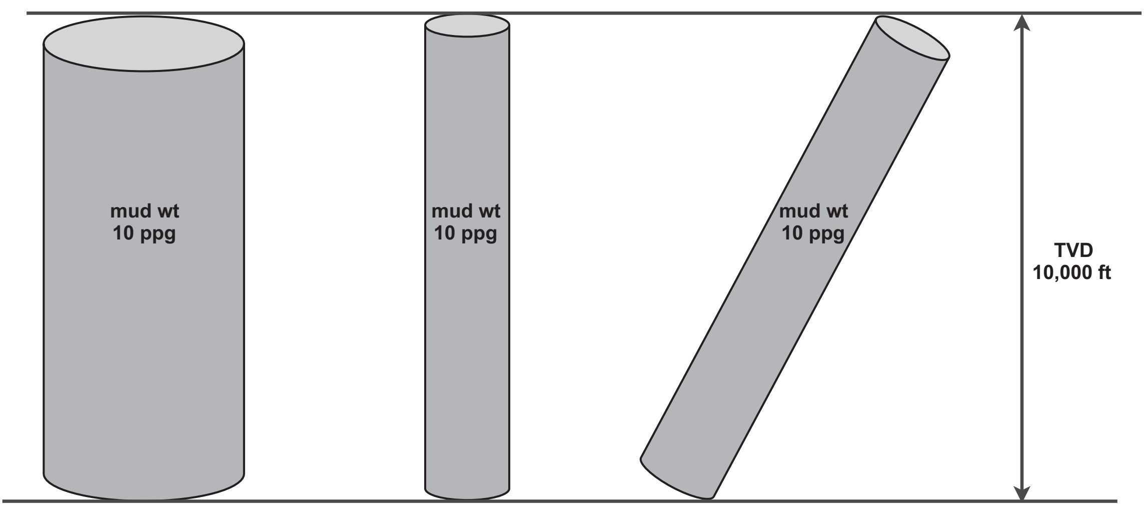
Hydrostatic Pressure (psi) = Mud Weight (ppg) x 0.052 x TVD (ft)

= 10 x 0.052 x 10,000

= <u>5,200 psi</u>

Hydrostatic pressure is only affected by mud weight and true vertical depth.

Well volume does not affect hydrostatic pressure. The pressure at the bottom of the three wells below will be exactly the same as they are full of the same mud and they have the same true vertical depth. This is important to remember.



Hydrostatic Pressure (psi) = 10 x 0.052 x 10,000 = <u>5,200 psi</u>

Let's have a quick summary of what you have learned so far about pressure.

Pressure gradient is how much pressure will change by every foot. It is expressed in psi/ft.

The pressure gradient of 1 ppg mud is 0.052 psi/ft.

0.052 is an important constant used in pressure calculations.

The formula to work out the pressure gradient for any mud weight is:

Pressure Gradient (psi/ft) = Mud Weight (ppg) x 0.052

Hydrostatic pressure is the pressure exerted by a column of fluid at rest.

The main hydrostatic pressure formula is:

Hydrostatic Pressure (psi) = Mud Weight (ppg) x 0.052 x TVD (ft)

You can also use:

Hydrostatic Pressure (psi) = Pressure Gradient (psi/ft) x TVD (ft)

Well measured depth and hole volume do not affect hydrostatic pressure.

Hydrostatic pressure is only affected by the mud weight and the true vertical depth of the mud column.

Calculate the hydrostatic pressure at the bottom of the following wells.

1) Mud weight = 13.4 ppg; TVD = 11,456 ft

2) Mud gradient = 0.6656 psi/ft; MD = 13,789 ft; TVD = 12,345 ft

3) TVD = 6,356 ft; MD = 6,356 ft; Mud Weight = 9.7 ppg

4) MD = 17,333 ft; Mud Gradient = 0.7696 psi/ft; TVD = 16,887 ft

Answer to nearest whole psi.

ANSWERS

Hydrostatic Pressure (psi) = Mud Weight (ppg) x 0.052 x TVD (ft)

OR

Hydrostatic Pressure (psi) = Pressure Gradient (psi/ft) x TVD (ft)

---

1) Hydrostatic Pressure (psi) = 13.4 x 0.052 x 11,456

= <u>7,983 psi</u>

---

2) Hydrostatic Pressure (psi) = 0.6656 x 12,345 (TVD Remember)

= <u>8,217 psi</u>

---

3) Hydrostatic Pressure (psi) = 9.7 x 0.052 x 6,356

= <u>3,206 psi</u>

---

4) Hydrostatic Pressure (psi) = 0.7696 x 16,887

= <u>12,996 psi</u>

Once again you will have had no great problems with these calculations. By now you may be getting tempted to do away with some of the calculation discipline you learned in the first chapter. You may be thinking to yourself:

"These calculations are easy, why bother with all the writing? I can do them straight in the calculator."

CONTINUE TO WRITE EACH CALCULATION DOWN COMPLETE WITH <u>ANSWER & UNIT UNDERLINED</u>.

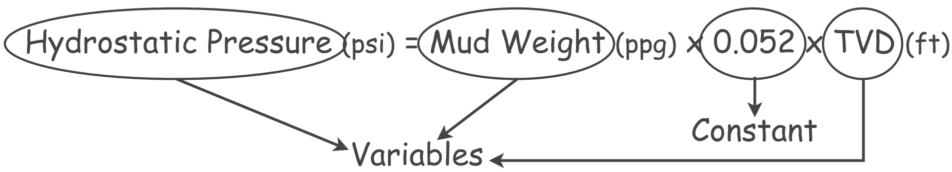
CONTINUE TO SEPARATE EACH QUESTION ON THE PAGE.

IT IS WORKING - WHY FIX IT?

VARIATIONS ON THE HYDROSTATIC PRESSURE FORMULA

In chapter one of this book you mastered the art of rearranging formulas so this next bit is going to be a breeze.

The hydrostatic pressure formula has one constant and three variables:



The standard version of the formula, shown above, allows you to work out hydrostatic pressure if you know the mud weight and the true vertical depth.

The formula can be rearranged to allow you to work out mud weight if you know hydrostatic pressure and true vertical depth:

Hydrostatic Pressure (psi) = Mud Weight (ppg) x 0.052 x TVD (ft)

Hydrostatic Pressure (psi) ÷ TVD (ft) = Mud Weight (ppg) x 0.052

Hydrostatic Pressure (psi) ÷ TVD (ft) ÷ 0.052 = Mud Weight (ppg)

which can be flipped to read

Mud Weight (ppg) = Hydrostatic Pressure (psi) ÷ TVD (ft) ÷ 0.052

Can you rearrange the main hydrostatic pressure formula to work out TVD?

Hydrostatic Pressure (psi) = Mud Weight (ppg) x 0.052 x TVD (ft)

ANSWER

Hydrostatic Pressure (psi) = Mud Weight (ppg) x 0.052 x TVD (ft)

Hydrostatic Pressure (psi) ÷ Mud Weight (ppg) = 0.052 x TVD (ft)

Hydrostatic Pressure (psi) ÷ Mud Weight (ppg) ÷ 0.052 = TVD (ft)

which can be flipped to read

TVD (ft) = Hydrostatic Pressure (psi) ÷ Mud Weight (ppg) ÷ 0.052

You now have the basic hydrostatic pressure formula and two variations:

Hydrostatic Pressure (psi) = Mud Weight (ppg) x 0.052 x TVD (ft)

Mud Weight (ppg) = Hydrostatic Pressure (psi) ÷ TVD (ft) ÷ 0.052

TVD (ft) = Hydrostatic Pressure (psi) ÷ Mud Weight (ppg) ÷ 0.052

You can use these formulas to work out most pressure calculations.

The versions shown above are said to be *"calculator friendly"* formulas. This means you can do the complete calculation, in your calculator, in one go, by starting at the left and working right following the formula.

What is the mud weight if the hydrostatic pressure is 5,200 psi and TVD is 10,000 ft?

Mud Weight (ppg) = Hydrostatic Pressure (psi) ÷ TVD (ft) ÷ 0.052

= 5,200 ÷ 10,000 ÷ 0.052

Start by entering 5200 and work right, entering everything as shown in the formula, until you reach the end, then hit = to get the final answer.

= <u>10 ppg</u>

The two variations are sometimes given a slightly different way:

$$\text{Mud Weight (ppg)} = \frac{\text{Hydrostatic Pressure (psi)}}{\text{TVD (ft)} \times 0.052}$$

$$\text{TVD (ft)} = \frac{\text{Hydrostatic Pressure (psi)}}{\text{Mud Weight (ppg)} \times 0.052}$$

These versions are deemed to be more mathematically correct ways to write the formulas. You learned how to work with formulas like these in chapter one. Whichever version you are given the answer will work out the same.

Let's just confirm that using the example opposite:

What is the mud weight if the hydrostatic pressure is 5,200 psi and TVD is 10,000 ft?

$$\text{Mud Weight (ppg)} = \frac{\text{Hydrostatic Pressure (psi)}}{\text{TVD (ft)} \times 0.052}$$

$$= \frac{5{,}200}{10{,}000 \times 0.052}$$

$$= \frac{5{,}200}{520}$$

$$= \underline{10 \text{ ppg}}$$

Work out the following using the formulas above:

1) What is TVD? Hydrostatic Pressure = 7,420 psi; Mud Weight = 11.3 ppg

2) What is Mud Weight? TVD = 7,845 ft; Hydrostatic Pressure = 4,680 psi

3) What is TVD? Mud gradient = 0.5616 psi/ft; Hydrostatic Pressure = 8,424 psi

ANSWERS

1)

$$TVD\ (ft) = \frac{\text{Hydrostatic Pressure (psi)}}{\text{Mud Weight (ppg)} \times 0.052}$$

$$= \frac{7{,}420}{11.3 \times 0.052}$$

$$= \frac{7{,}420}{0.5876}$$

$$= \underline{12{,}628\ ft}$$

---

2)

$$\text{Mud Weight (ppg)} = \frac{\text{Hydrostatic Pressure (psi)}}{TVD\ (ft) \times 0.052}$$

$$= \frac{4{,}680}{7{,}845 \times 0.052}$$

$$= \frac{4{,}680}{407.94}$$

$$= \underline{11.47\ ppg}$$

3) Whoa where did that one come from?

For this one you could convert the pressure gradient to a mud weight using the formula we used earlier.

You could...........................

However look what is below the line in the TVD formula:

$$\text{TVD (ft)} = \frac{\text{Hydrostatic Pressure (psi)}}{\text{Mud Weight (ppg)} \times 0.052}$$

this works out pressure gradient

In this question you can replace the two numbers below the line with pressure gradient which is what they work out anyway. This means:

$$\text{TVD (ft)} = \frac{\text{Hydrostatic Pressure (psi)}}{\text{Pressure Gradient (psi/ft)}}$$

$$= \frac{8{,}424}{.5616}$$

$$= \underline{15{,}000 \text{ ft}}$$

Things are starting to get a little bit busy now as far as hydrostatic pressure is concerned. We seem to have an awful lot of formulas. There would appear to be more than one way to work out the answers. When do you use what? Why and how and where? Panic!

DON'T PANIC

The hydrostatic pressure formula underpins most well control calculations (next book) and many of the pressure calculations relating to well bore pressure (this book). Yes, there are a few different ways of writing things down in a formula. But are there really lots of different formulas, or just different ways of looking at the same basic information?

Let's look at them one by one, starting with the hydrostatic pressure formula.

Hydrostatic Pressure (psi) = Mud Weight (ppg) x 0.052 x TVD (ft)

The first thing you do in this formula is multiply mud weight by 0.052. This is equal to pressure gradient. The first thing you do in this formula is work out pressure gradient in psi/ft. If you multiply that by the total number of feet you will get pressure. Hence:

Hydrostatic Pressure (psi) = Pressure Gradient (psi/ft) x TVD (ft)

So are these formulas really different from each other? The answer has to be a firm no. They may seem to use different information but they don't really.

Remember, mud weight and pressure gradient are two different ways of saying the same thing. They are related to each other by the constant 0.052. If you have one you have the other.

What you have here is one formula shown at two different stages.

It is important you understand the relationship between mud weight and pressure gradient.

Next, let's look at working out TVD.

We have:

$$\text{TVD (ft)} = \text{Hydrostatic Pressure (psi)} \div \text{Mud Weight (ppg)} \div 0.052$$

$$\text{TVD (ft)} = \frac{\text{Hydrostatic Pressure (psi)}}{\text{Mud Weight (ppg)} \times 0.052}$$

Here the same information is used in both formulas. You have the same formula written two different ways - one being calculator friendly, and the other, more mathematically correct.

The other TVD formula is the same as the second one above, just one stage into the calculation as mud weight x 0.052 = pressure gradient.

$$\text{TVD (ft)} = \frac{\text{Hydrostatic Pressure (psi)}}{\text{Pressure Gradient (psi/ft)}}$$

Finally, we have two formulas for mud weight.

$$\text{Mud Weight (ppg)} = \text{Hydrostatic Pressure (psi)} \div \text{TVD (ft)} \div 0.052$$

$$\text{Mud Weight (ppg)} = \frac{\text{Hydrostatic Pressure (psi)}}{\text{TVD (ft)} \times 0.052}$$

Once again these are just two different ways of writing down the same information - calculator friendly and mathematically correct.

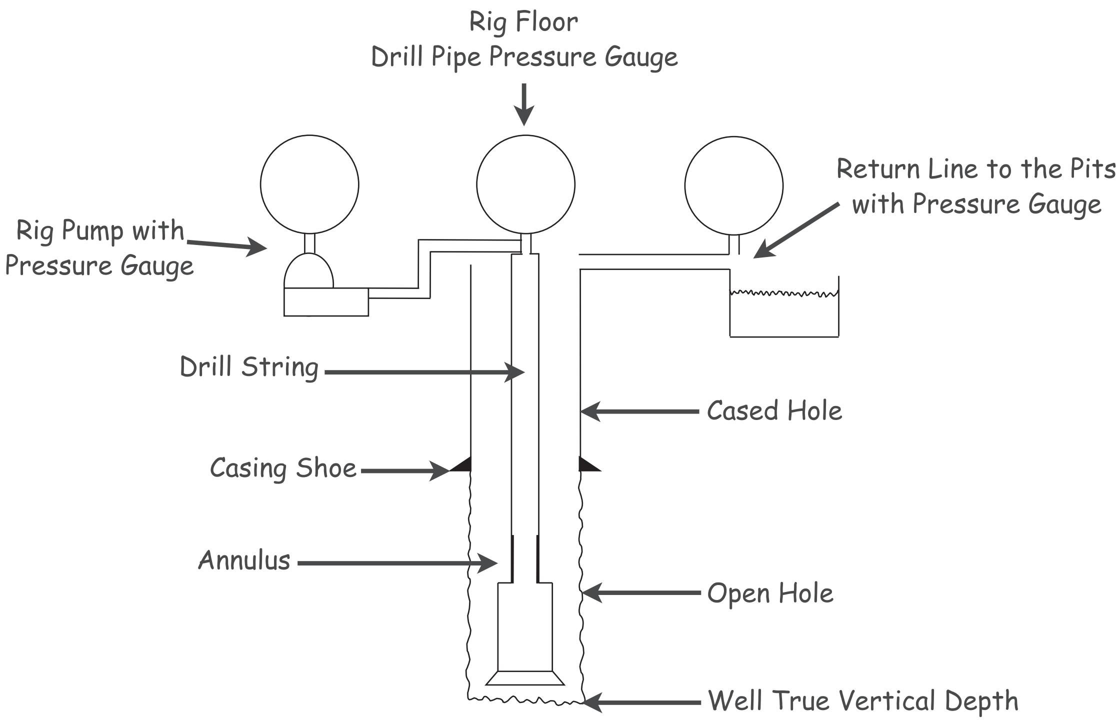
The main thing to remember is that a formula is just a set of instructions for a calculation. Do the calculation properly and you will get the correct answer.

The words "Hydrostatic Pressure" can be replaced by the word "Pressure" in these formulas which will allow you to use them for calculations not using hydrostatic pressure.

CIRCULATING PRESSURES

So far in this book you have looked at the hydrostatic condition. Hydrostatic - fluid not moving. In order to drill a well you need to circulate the mud. When you get the mud moving, things change.

The picture below shows a basic well, similar to the one you looked at in chapter two, but with a few extra bits added.



If the well TVD was 10,000 ft, and it was full of 10 ppg mud then the hydrostatic pressure at the bottom of the well would be:

$$\text{Hydrostatic Pressure (psi)} = \text{Mud Weight (ppg)} \times 0.052 \times \text{TVD (ft)}$$

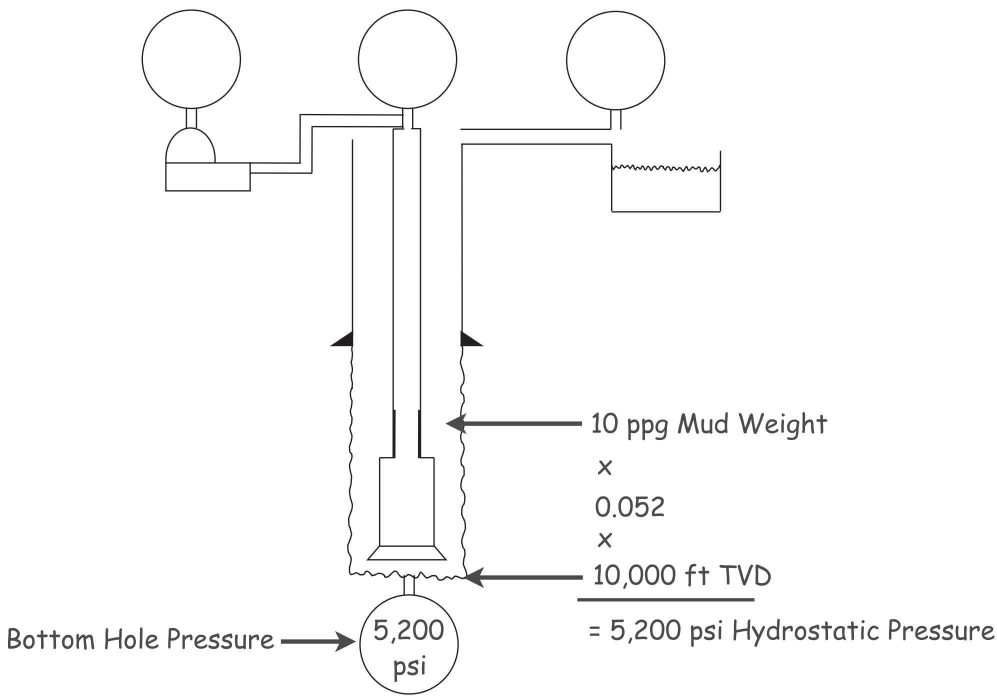
$$= 10 \times 0.052 \times 10{,}000$$

$$= \underline{5{,}200 \text{ psi}}$$

The hydrostatic pressure exerted by the column of mud in this well is 5,200 psi. You have worked that out using the formula.

If you could plumb a pressure gauge in at the bottom of the hole it would measure the pressure pushing down on the bottom of the hole. At the moment that gauge would read 5,200 psi.

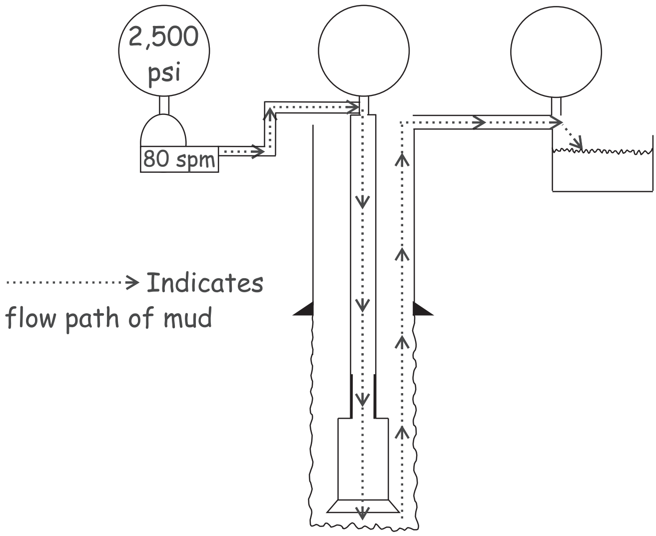
At the moment, both hydrostatic pressure and bottom hole pressure are the same value - they are both 5,200 psi.



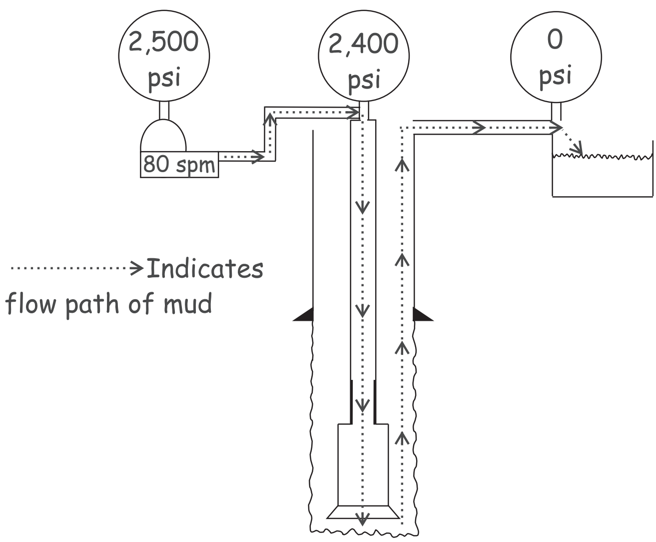
If the mud weight remains 10 ppg, and the well TVD remains 10,000 ft, then hydrostatic pressure will not change.

But what happens to bottom hole pressure when you are circulating?

First up, let's start pumping at 80 strokes per minute (spm). When this happens you will get a reading on the rig pump pressure gauge, say 2,500 psi. This pressure is as a result of the friction that has to be overcome to circulate the mud through the entire system.



The pressure gauge on the rig floor will read a lower value than the one on the pump, and the gauge at the end of the circulating system will read zero.



Pressure is a result of friction as mud is circulated round the system. In this example the total pressure required to overcome friction and get the mud all the way round the system is 2,500 psi (the value you can read on the pump gauge).

This is the amount of effort the pump has to put out to get the mud up to the rig floor, down the inside of the drill string, out the bit and back up the annulus to surface.

When the mud gets back to surface there will be no circulating pressure left. The work has been done by this stage. That is why the gauge at the end of the system reads zero (you will not normally have a gauge there on a rig).

The gauge on the rig floor is reading 2,400 psi. What is this telling you?

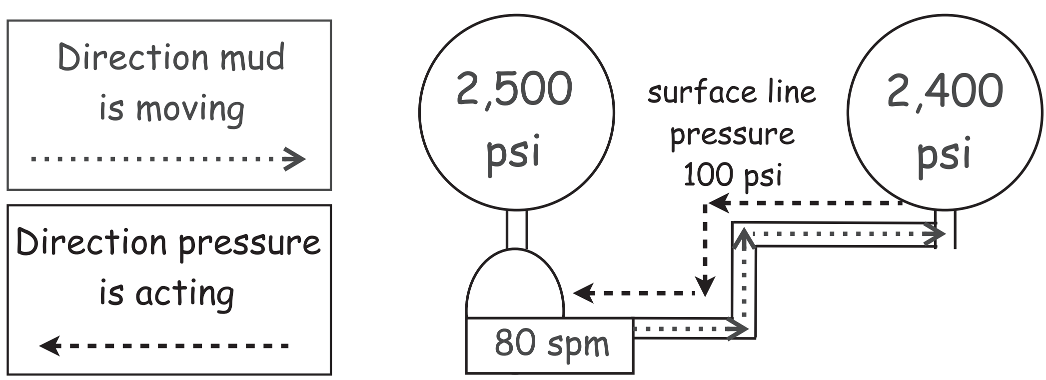
It is telling you three things:

1) It is telling you that it takes 100 psi of pressure to overcome friction in the surface lines and get the mud up to the rig floor.

2) It is telling you that it takes 2,400 psi of pressure to overcome friction and get the mud the rest of the way round the system.

3) It is telling you that circulating pressure acts opposite to the direction of travel.

   The rig floor gauge is reading 2,400 psi, and the pump gauge is reading 2,500 psi. The mud is moving from the pump to the rig floor, the pressure required to overcome the friction in the surface lines (100 psi) is acting back on the pump - opposite to the direction the mud is moving.

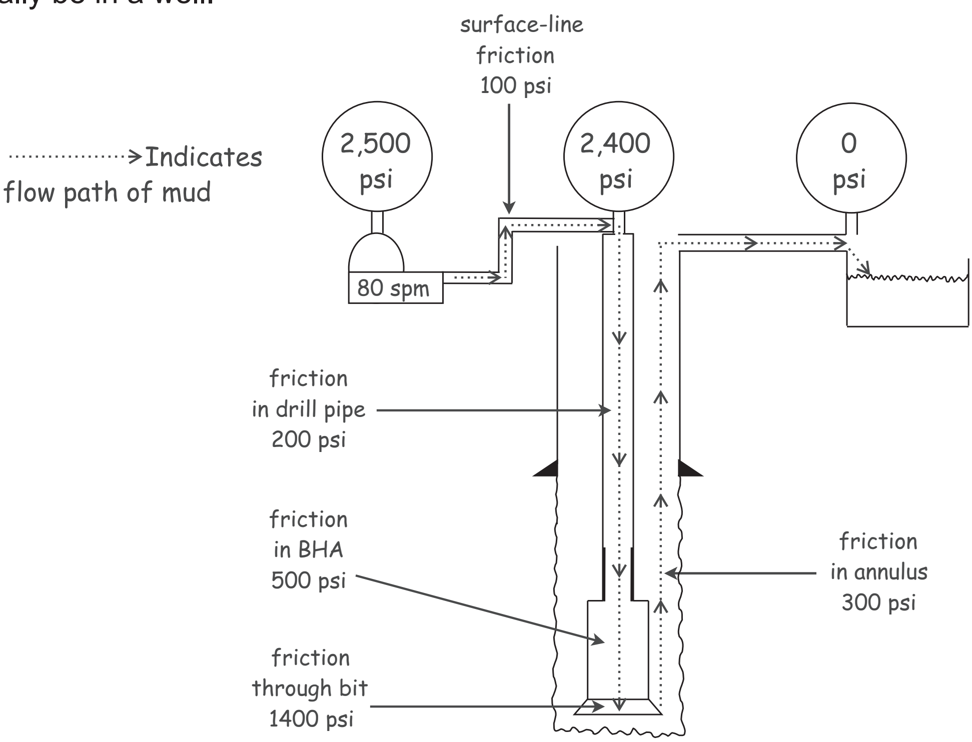


This is an important principle to understand. The pressure required to overcome friction is sometime referred to as circulating pressure loss.

Pressure is needed to overcome friction as mud is circulated round the system. You can see all of the pressure needed for circulation on the pump gauge and none of it at the end of the system.

If you plumb in a pressure gauge anywhere in the system you would be able to measure the remaining pressure required to overcome friction. This tells you that circulating pressure acts opposite to the direction the mud is travelling. You saw this in action as the difference in pressure between the pump gauge and the rig floor gauge.

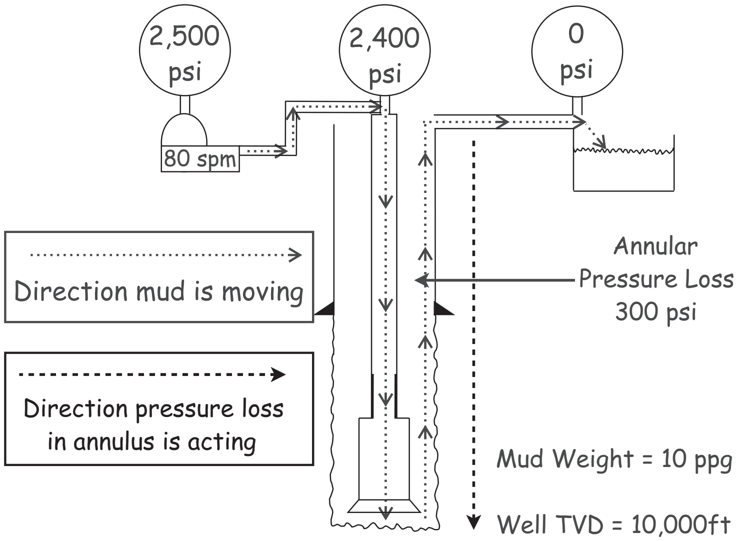
Friction varies in the different sections of the circulating system. The diagram below gives an indication of the different friction pressures. The values used are to explain what is happening and do not necessarily reflect what they may actually be in a well.



If you add all the friction pressure values together they will equal the reading on the pump gauge, this is your total circulating pressure:

$$100 + 200 + 500 + 1400 + 300 = 2{,}500 \text{ psi}$$

Pressure acts opposite to the direction of travel. The mud is travelling up the annulus. This must mean that the friction in the annulus is acting back down on to the bottom of the hole. This friction is often called Annular Pressure Loss (APL).



Before circulation started, both bottom hole pressure and hydrostatic pressure were equal to 5,200 psi: 10 x 0.052 x 10,000 = 5,200

Mud weight and TVD do not change when the pump is running, so hydrostatic pressure is still the same. Hydrostatic pressure is still acting on the bottom of the hole.

Annular pressure loss (APL) is now also acting on the bottom of the hole.

Bottom hole circulating pressure (BHCP) can be worked out using the formula:

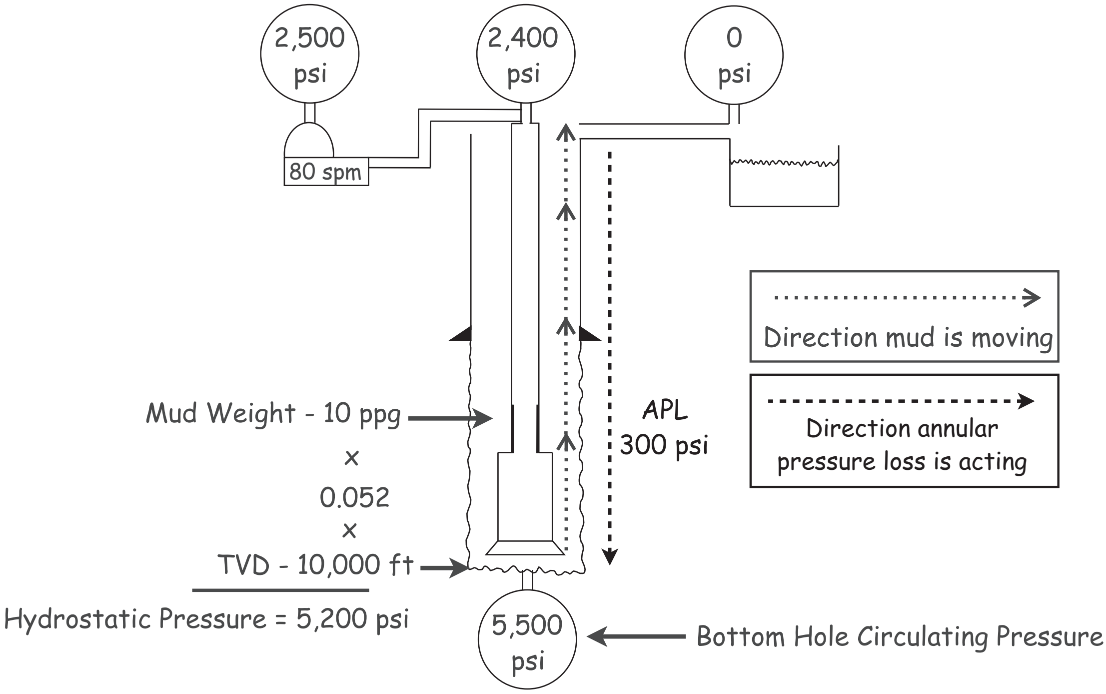
BHCP (psi) = Hydrostatic Pressure in the Annulus (psi) + APL (psi)

= 5,200 + 300 = 5,500 psi

When you are circulating, bottom hole pressure increases by an amount equal to annular pressure loss.

When you switch off the pump, bottom hole pressure will fall by an amount equal to APL.

Bottom hole pressure increases by an amount equal to annular pressure loss when you are circulating as you see below.



BHCP is 5,500 psi. It is a combination of mud hydrostatic pressure and APL.

What mud weight would you need to have in the hole to create a hydrostatic pressure of 5,500 psi at 10,000 ft?

You can use one of the variations of the hydrostatic pressure formula:

Mud Weight (ppg) = Pressure (psi) ÷ TVD (ft) ÷ 0.052

where you use BHCP as the pressure value in the formula. This gives:

= 5,500 ÷ 10,000 ÷ 0.052 = 10.58 ppg

This mud weight is know as Equivalent Circulating Density. If you had 10.58 ppg mud in the hole, then it would give you 5,500 psi of pressure hydrostatically.

Check that quickly:

$$\text{Hydrostatic Pressure (psi)} = \text{Mud Weight (ppg)} \times 0.052 \times \text{TVD (ft)}$$

$$= 10.58 \times 0.052 \times 10{,}000$$

$$= \underline{5{,}502 \text{ psi}}$$

Near enough the same pressure. The extra 2 psi have come from the fact that the mud weight was rounded to 10.58 from 10.57692307.

There is a formula that can be used to work out ECD:

$$\text{ECD (ppg)} = \frac{\text{APL (psi)}}{\text{TVD (ft)} \times 0.052} + \text{Current Mud Weight (ppg)}$$

Try that out for the figures opposite:

$$\text{ECD (ppg)} = \frac{300}{10{,}000 \times 0.052} + 10$$

$$= \frac{300}{520} + 10 = \underline{10.58 \text{ ppg}}$$

Answer the following to nearest psi with mud weights to 2 decimals:

1) What is ECD? TVD = 8,455 ft; Mud Wt. = 9.7 ppg; APL = 425 psi

2) What is ECD? TVD = 11,786 ft; BHCP = 6,433 psi

3) What is BHCP? TVD = 12,550 ft; Mud Wt. = 12.3 ppg; APL = 370 psi

4) What is APL? Mud Wt. = 13.4 ppg; TVD = 10,800 ft; BHCP = 7,845 psi

5) What will the pump gauge be reading?
BHCP = 6,250 psi; TVD = 9,450 ft; Mud Wt. = 12 ppg;
Surface line friction = 125 psi; Drill string friction = 310 psi;
BHA friction = 470 psi; Friction through bit = 1450 psi

ANSWERS

1) $$\text{ECD (ppg)} = \frac{425}{8{,}455 \times 0.052} + 9.7$$

$$= \frac{425}{439.66} + 9.7 = \underline{10.67 \text{ ppg}}$$

The ECD formula also comes in a calculator friendly version:

ECD (ppg)= (APL (psi) ÷ TVD (ft) ÷ 0.052) + Current Mud Weight (ppg)

which works out as:

ECD (ppg)= (425 ÷ 8,455 ÷ 0.052) + 9.7 = 10.67 ppg

---

2) Mud Weight (ppg) = Pressure (psi) ÷ TVD (ft) ÷ 0.052

If you use BHCP as the value for pressure then the mud weight you calculate will be ECD.

ECD (ppg) = 6,433 ÷ 11,786 ÷ 0.052 = 10.5 ppg

---

3) BHCP (psi) = Hydrostatic Pressure in the Annulus (psi) + APL (psi)

You first need to work out hydrostatic pressure:

Hydrostatic Pressure (psi) = Mud Weight (ppg) x 0.052 x TVD (ft)

= 12.3 x 0.052 x 12,550 = 8,027 psi

BHCP (psi)= Hydrostatic Pressure in the Annulus (psi) + APL (psi)

= 8,027 + 370 = 8,397 psi

4) BHCP (psi) = Hydrostatic Pressure in the Annulus (psi) + APL (psi)

which rearranges to give:

APL (psi) = BCHP (psi) - Hydrostatic Pressure in the Annulus (psi)

Hydrostatic Pressure (psi) = Mud Weight (ppg) x 0.052 x TVD (ft)

= 13.4 x 0.052 x 10,800 = 7,525 psi

APL (psi) = BCHP (psi) - Hydrostatic Pressure in the Annulus (psi)

= 7,845 - 7,525 = 320 (psi)

---

5) The pump pressure gauge will show the total system circulating pressure.

You need to work out APL first.

APL (psi) = BCHP (psi) - Hydrostatic Pressure in the Annulus (psi)

Hydrostatic Pressure (psi) = Mud Weight (ppg) x 0.052 x TVD (ft)

= 12 x 0.052 x 9,450 = 5,897 psi

APL (psi) = BCHP (psi) - Hydrostatic Pressure in the Annulus (psi)

= 6,250 - 5,897 = 353 (psi)

Pump Pressure (psi) = 125 + 310 + 470 + 1450 + 353

= 2,708 psi

CHANGE OF PUMP SPEED

If you change your pump speed, then pump pressure will also change. If the pump speed is increased, then the pump pressure will go up. It has to. The pump will be working harder so the amount of energy required will be greater. If the pump is slowed down, then the pump pressure will reduce.

There is a formula that can be used to give you an approximate idea of what will happen to the pump pressure if you change your pump speed:

$$\text{New Pressure at New Pump Speed (psi)} = \left[\frac{\text{New Pump Speed (spm)}}{\text{Old Pump Speed (spm)}}\right]^2 \times \text{Pressure at Old Pump Speed (psi)}$$

The pump pressure at 80 spm was 2,500 psi. What will the pressure be if the pump is slowed down to 30 spm?

$$\text{New Pressure at New Pump Speed (psi)} = \left[\frac{\text{New Pump Speed (spm)}}{\text{Old Pump Speed (spm)}}\right]^2 \times \text{Pressure at Old Pump Speed (psi)}$$

$$= \left[\frac{30}{80}\right]^2 \times 2{,}500$$

$$= 0.375^2 \times 2{,}500$$

$$= 0.140625 \times 2{,}500$$

$$= \underline{352 \text{ psi}}$$

The formula can be used to calculate what the new pump pressure will be if the pump speed is increased or decreased.

CHANGE OF MUD WEIGHT

The pump pressure will also be affected if you change your mud weight. If you have lighter mud then there will generally be less solids in the mud which means there will be less friction and therefore it will be easier to pump. The pump pressure will drop. If you have heavier mud then the pump pressure will increase.

There is a formula that can be used to give you an approximate idea of what will happen to the pump pressure if you change your mud weight:

$$\text{New Pressure with New Mud Weight (psi)} = \frac{\text{New Mud Weight (ppg)}}{\text{Old Mud Weight (ppg)}} \times \text{Pressure with Old Mud Weight (psi)}$$

The pump pressure with 10 ppg was 2,500 psi. What will the pressure be if the mud weight is increased to 12 ppg?

$$\text{New Pressure with New Mud Weight (psi)} = \frac{\text{New Mud Weight (ppg)}}{\text{Old Mud Weight (ppg)}} \times \text{Pressure with Old Mud Weight (psi)}$$

$$= \frac{12}{10} \times 2{,}500 = 1.2 \times 2{,}500 = \underline{3{,}000 \text{ psi}}$$

Work out the new pressure in the following, to the nearest psi.

1) Old spm = 45; new spm = 120; old pressure = 450 psi

2) The current pump pressure is 3,450 psi at 60 spm. The pump speed must be reduced to 45 spm.

3) New mud wt. = 14.6 ppg; old mud wt. = 13.3 ppg; old pressure = 1,280 psi

4) The current pump pressure is 4,300 psi with 9.5 ppg mud. The mud weight is reduced to 9.2 ppg.

5) The current pump pressure is 2,700 psi with 10.7 ppg mud at 85 spm. The pump speed is increased to 105 spm. The mud weight is increased to 11.1 ppg.

ANSWERS

1) $$\text{New Pressure at New Pump Speed (psi)} = \left[\frac{\text{New Pump Speed (spm)}}{\text{Old Pump Speed (spm)}}\right]^2 \times \text{Pressure at Old Pump Speed (psi)}$$

$$= \left[\frac{120}{45}\right]^2 \times 450$$

$$= 2.666666666^2 \times 450 = 7.111111107 \times 450 = \underline{3,200\ \text{(psi)}}$$

---

2) $$\text{New Pressure at New Pump Speed (psi)} = \left[\frac{45}{60}\right]^2 \times 3,450$$

$$= 0.75^2 \times 3,450 = 0.5625 \times 3,450 = \underline{1,941\ \text{(psi)}}$$

---

3) $$\text{New Pressure with New Mud Weight (psi)} = \frac{\text{New Mud Weight (ppg)}}{\text{Old Mud Weight (ppg)}} \times \text{Pressure with Old Mud Weight (psi)}$$

$$= \frac{14.6}{13.3} \times 1,280 = 1.09774436 \times 1,280 = \underline{1,405\ \text{psi}}$$

---

4) $$\text{New Pressure with New Mud Weight (psi)} = \frac{9.2}{9.5} \times 4,300 = 0.968421052 \times 4,300 = \underline{4,164\ \text{psi}}$$

5) This time there has been a change in pump speed and a change in mud weight. You have to use both formulas one at a time. You can start with either one, but you must take the answer to the first calculation as the old pressure for the second one.

Changing pump speed first you get:

$$\text{New Pressure at New Pump Speed (psi)} = \left[\frac{105}{85}\right]^2 \times 2{,}700$$

$$= 1.235294117^2 \times 2{,}700 = 1.525951555 \times 2{,}700 = \underline{4{,}120\ \text{(psi)}}$$

This answer is now used as the old pressure in the mud weight change calculation:

$$\text{New Pressure with New Mud Weight (psi)} = \frac{11.1}{10.7} \times 4{,}120 = 1.037383177 \times 4{,}120 = \underline{4{,}274\ \text{psi}}$$

If you do the change of mud weight calculation first, then change the pump speed you will get:

$$\text{New Pressure with New Mud Weight (psi)} = \frac{11.1}{10.7} \times 2{,}700 = 1.037383177 \times 2{,}700 = \underline{2{,}801\ \text{psi}}$$

$$\text{New Pressure at New Pump Speed (psi)} = \left[\frac{105}{85}\right]^2 \times 2{,}801$$

$$= 1.235294117^2 \times 2{,}801 = 1.525951555 \times 2{,}801 = \underline{4{,}274\ \text{(psi)}}$$

The answer works out the same regardless.

These formulas are similar - use the correct formula and make sure you put the correct values above and below the line - it is easy to get them the wrong way round if you're in a hurry. Take your time.

FORMATION STRENGTH

Hydrostatic pressure acts down on to the bottom of the hole. You need to have enough hydrostatic pressure to make sure the well does not flow until you are ready for it to flow. This is well control and will be covered in the next chapter.

You could ask "Why don't we just apply lots of hydrostatic pressure to the well, then it won't flow?"

This would seem to be a good solution to the well control issue, however, for a number of reasons, you cannot do this. Operationally, having excess hydrostatic pressure can mean much slower drilling. More importantly, it is possible to damage the formation by putting too much pressure on it. This can cause losses to the formation, which in turn, can lead to even greater well control problems.

You need to make sure you are applying enough hydrostatic pressure that the well does not flow, but not too much that you cause it to break down. How do you work out the strength of the formation?

One common way is to conduct a leak-off test. There are many ways to conduct a leak-off test and each company will have its own way of doing it. What follows is a basic description of a leak off test. Always ensure you follow your own company procedure for any operations you conduct.

As a rule of thumb, the deeper you go, the greater the formation strength. When you run casing you protect that section of the well. The section of open hole that is nearest surface is usually deemed to be the weakest. This is the section nearest to the casing shoe.

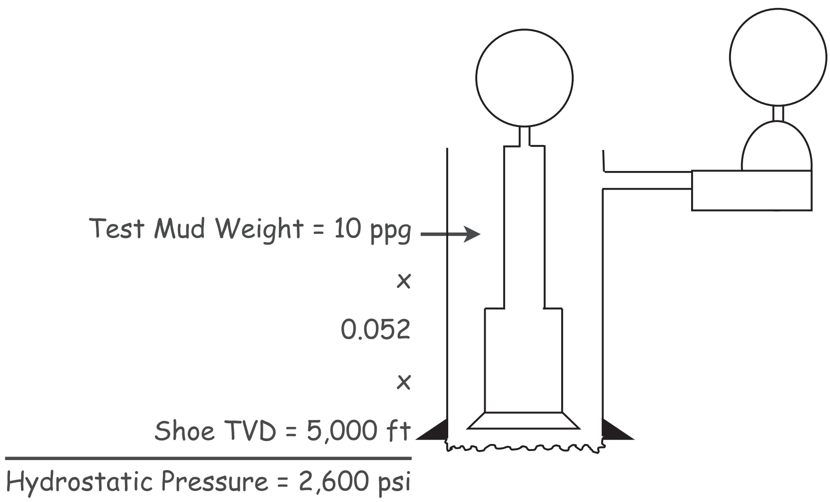
A leak-off test is generally conducted after you have run and cemented casing, then drilled out the casing shoe, rat hole and about 10 to 15 feet of open hole. This allows you to determine the strength of the new formation before drilling any further into it.

Once you have drilled the new formation you should circulate the hole totally clean. There should be no cuttings of any kind coming back - just clean mud.

Why?

You want clean mud in the hole so that you can accurately calculate the hydrostatic pressure in the hole. If it was loaded out with cuttings you would not really know what the mud weight in the annulus was.

How much hydrostatic pressure is being applied to the shoe in the well below?



This hydrostatic pressure will be applied to the shoe if you have 10 ppg mud in the hole. It will be acting on the shoe during the leak-off test.

Once you have circulated the hole clean it is good practice to pull back into the casing shoe. This is to make sure you don't get stuck should the hole collapse on you during the test. You are about to apply pressure to it, after all.

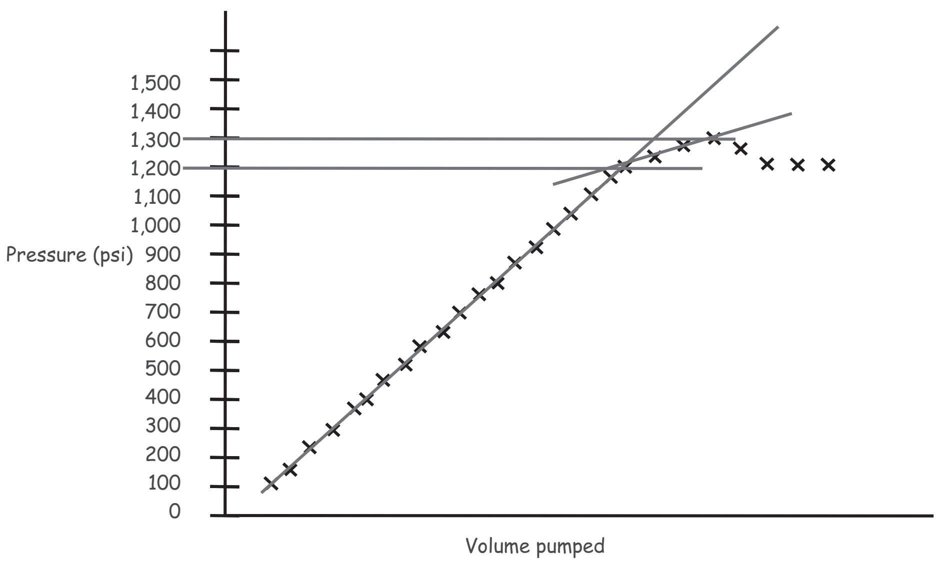
You will then line up at surface to pump slowly into a shut-in well. You may pump down the annulus, the drill string or a combination of both. It will depend on the rig equipment available and company or client procedures.

A cement pump or pressure test pump should be used to conduct the leak-off test. Rig pumps are not really suitable. The pump should be capable of maintaining a high pressure. It should also be equipped with an accurate pressure gauge.

OK - you have drilled some new hole; circulated the hole clean; pulled back into the shoe; shut the well in and lined up on a suitable pump. It is time to conduct the leak-off test by pumping slowly into the well.

The pressure will increase as fluid is pumped into the well. The pressure increase versus fluid pumped should be monitored during the test. As the pressure builds up this increase will show as a straight line on a graph. The leak-off pressure is said to be the point at which the pressure deviates away from the straight line.

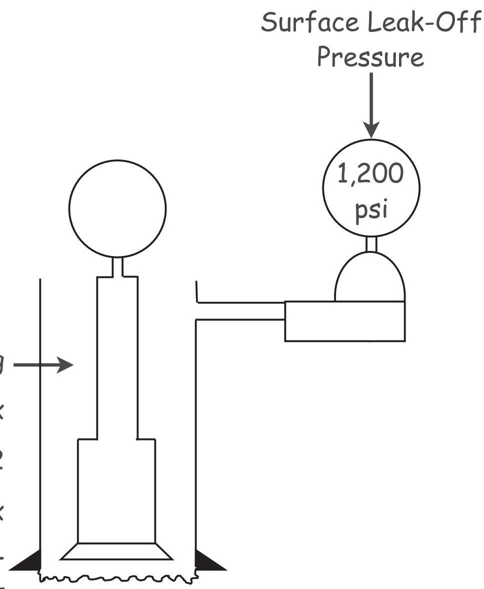
What is the leak-off pressure on the graph below?



The line breaks away from the straight at 1,200 psi. This will be the surface leak-off pressure value for this leak-off test. This is not the formation strength, however.

Formation strength, or fracture pressure, is the total pressure applied on the formation, at the shoe, during the leak-off test. This is a combination of two things - the hydrostatic pressure in the well at the leak-off test, and the surface leak-off pressure at the test.

Using the well below you can now work out the total pressure applied to the shoe at the leak-off test.



Test Mud Weight = 10 ppg

×

0.052

×

Shoe TVD = 5,000 ft

Hydrostatic Pressure = 2,600 psi

+

Surface Leak-Off Pressure = 1,200 psi

Fracture Pressure = 3,800 psi

In this example, fracture pressure is 3,800 psi.

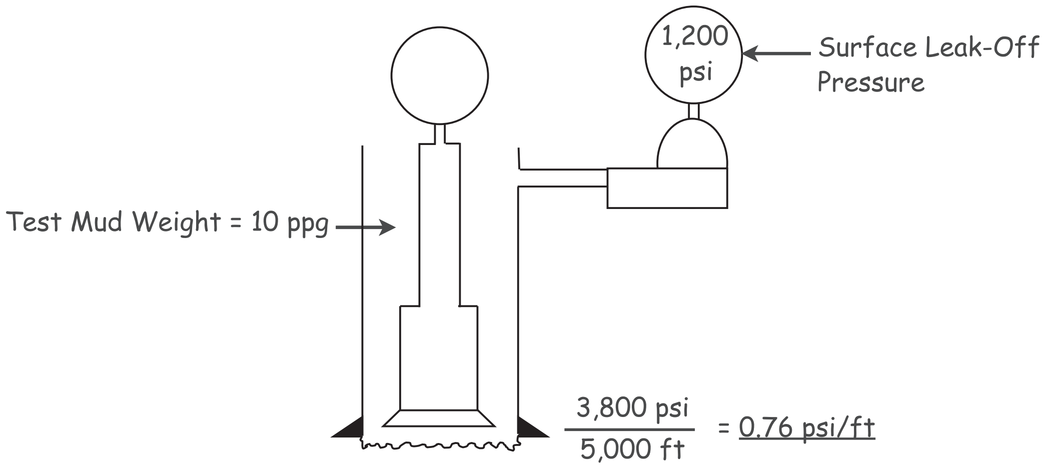
Fracture pressure is assumed to be the maximum pressure that can be applied to the shoe during subsequent operations.

As the well is drilled deeper, weaker fracture zones may be encountered, but for planning purposes this value is used.

Fracture pressure may also be called breakdown pressure.

MAXIMUM MUD WEIGHT

Fracture pressure at the shoe is 3,800 psi. The shoe is at 5,000 ft TVD. This could be written as a pressure gradient - 3,800 psi per 5,000 ft. What is this as a psi per foot pressure gradient?



$$\frac{3{,}800 \text{ psi}}{5{,}000 \text{ ft}} = \underline{0.76 \text{ psi/ft}}$$

This gradient is known as fracture gradient.

You will remember that pressure gradient and mud weight are the same thing.

What is 0.76 psi/ft as a mud weight?

$$\text{Mud Weight (ppg)} = \text{Pressure Gradient (psi/ft)} \div 0.052$$

$$= 0.76 \div 0.052 = 14.61538461 \text{ ppg}$$

This mud weight is known as maximum mud weight. If you had this mud weight in the hole, the hydrostatic pressure at the shoe would equal fracture pressure.

If it was rounded mathematically you would get a final answer of 14.62 ppg, which would give a hydrostatic pressure at the shoe of:

$$= 14.62 \times 0.052 \times 5{,}000 = \underline{3{,}801 \text{ psi}}$$

This is greater than fracture pressure. Maximum mud weight is not rounded up.

Maximum mud weight is taken at one decimal place as you read on your calculator. This is a rounding down, and gives a final answer of:

= <u>14.6 ppg</u>

The hydrostatic pressure this mud weight exerts is:

= 14.6 x 0.052 x 5,000 = <u>3,796 psi</u>

This is slightly less than fracture pressure so is ok.

There is a formula that can be used to work out maximum mud weight:

Max Mud Wt. (ppg) = (LOT Pressure (psi) ÷ Shoe TVD (ft) ÷ 0.052) + Test Mud Wt. (ppg)

For the example you have been using this comes to:

Max Mud Weight (ppg) = (1,200 ÷ 5,000 ÷ 0.052) + 10 = <u>14.6 ppg</u>

Work out the following:

1) What is the fracture pressure and maximum mud weight?

   LOT Pressure = 1,650 psi; Shoe TVD = 6,250 ft; Test Mud Wt.= 11.3 ppg

2) What is the maximum mud weight?

   Fracture pressure = 7,655 psi; Shoe TVD = 9,800 ft

3) What is the fracture gradient?

   Shoe TVD = 11,250 ft; LOT Pressure = 1,825 psi; Test Mud Wt = 13.2 ppg

4) What was the LOT Pressure?

   Shoe TVD = 7,900 ft; Test Mud Wt. = 12 ppg; Max Mud Wt. = 16.4 ppg

ANSWERS

1) Fracture Pressure = Shoe Hydrostatic Pressure + LOT Pressure

Shoe Hydrostatic Pressure = 11.3 x 0.052 x 6,250 = 3,673 psi

Fracture Pressure (psi) = 3,673 + 1,650 = 5,323 psi

There are a few ways to work out maximum mud weight from here. Using the maximum mud weight formula you get:

Max Mud Wt. (ppg) = (LOT Pressure (psi) ÷ Shoe TVD (ft) ÷ 0.052) + Test Mud Wt. (ppg)

= (1,650 ÷ 6,250 ÷ 0.052) + 11.3 = 16.3 ppg

This formula also comes in a mathematical version which has the same data and gives the same answer. You have the calculation skills to use this version if it is given:

$$\text{Max Mud Wt. (ppg)} = \frac{\text{LOT Pressure (psi)}}{\text{Shoe TVD (ft)} \times 0.052} + \text{Current Mud Weight (ppg)}$$

---

2) Fracture Gradient = Fracture Pressure ÷ Shoe TVD

= 7,655 ÷ 9,800 = 0.7811 psi/ft

Max Mud Weight (ppg) = Fracture Gradient (psi/ft) ÷ 0.052

= 0.7811 ÷ 0.052 = 15 ppg

3) Fracture Gradient = Fracture Pressure ÷ Shoe TVD

Fracture Pressure = Shoe Hydrostatic Pressure + LOT Pressure

Shoe Hydrostatic Pressure = 13.2 x 0.052 x 11,250 = <u>7,722 psi</u>

Fracture Pressure (psi) = 7,722 + 1,825 = <u>9,547 psi</u>

Fracture Gradient = 9,547 ÷ 11,250 = <u>0.8486 psi/ft</u>

---

4) Fracture Pressure = Shoe Hydrostatic Pressure + LOT Pressure

which can be re-arranged to work out LOT Pressure as:

LOT Pressure = Fracture Pressure - Shoe Hydrostatic Pressure

Hydrostatically, maximum mud weight will give you fracture pressure:

Fracture Pressure = 16.4 x 0.052 x 7,900 = <u>6,737 psi</u>

Shoe hydrostatic pressure with test mud is:

Shoe Hydrostatic Pressure = 12 x 0.052 x 7,900 = <u>4,930 psi</u>

Therefore:

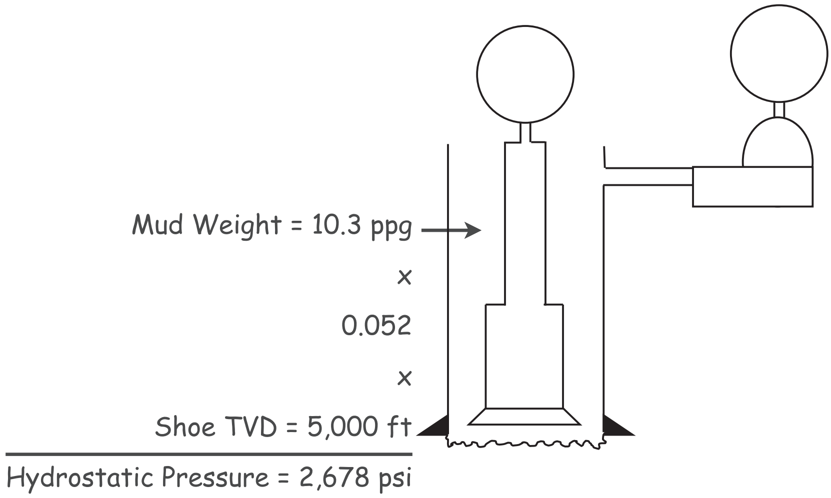
LOT pressure = Fracture Pressure - Shoe Hydrostatic Pressure

= 6,737 - 4,930 = <u>1,807 psi</u>

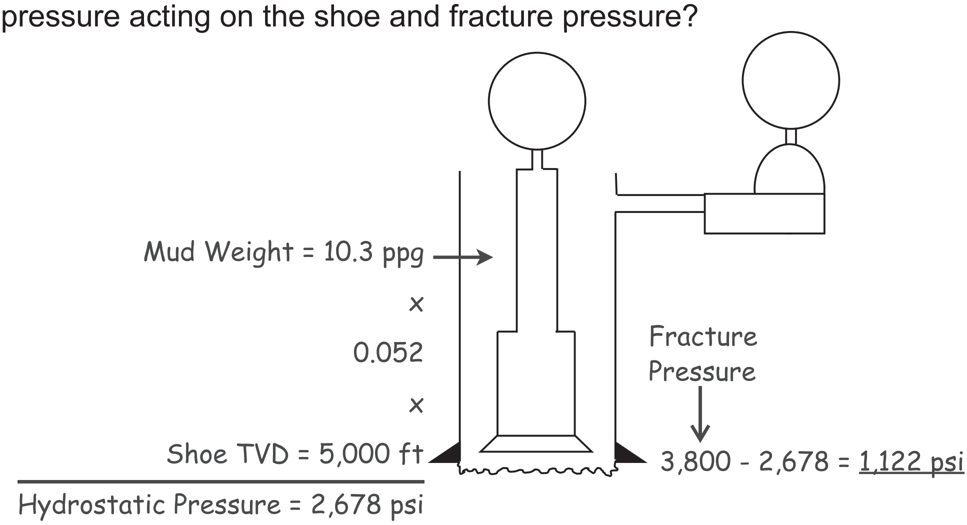
There are several different ways to work with these numbers. They all revolve around the same basic formulas. See if you can figure out a different way to tackle Question 4.

MAASP

Fracture pressure is the maximum pressure the shoe can withstand before it breaks down. What pressure is currently acting on the shoe in the well below?



This is the same well you have just conducted the leak-off test on, and you know that the fracture pressure is 3,800 psi. This is the maximum pressure that can be applied to the shoe. With 10.3 ppg mud in the hole you are currently applying 2,678 psi of pressure to the shoe. What is the difference between the current pressure acting on the shoe and fracture pressure?



You currently have 1,122 psi of spare pressure.

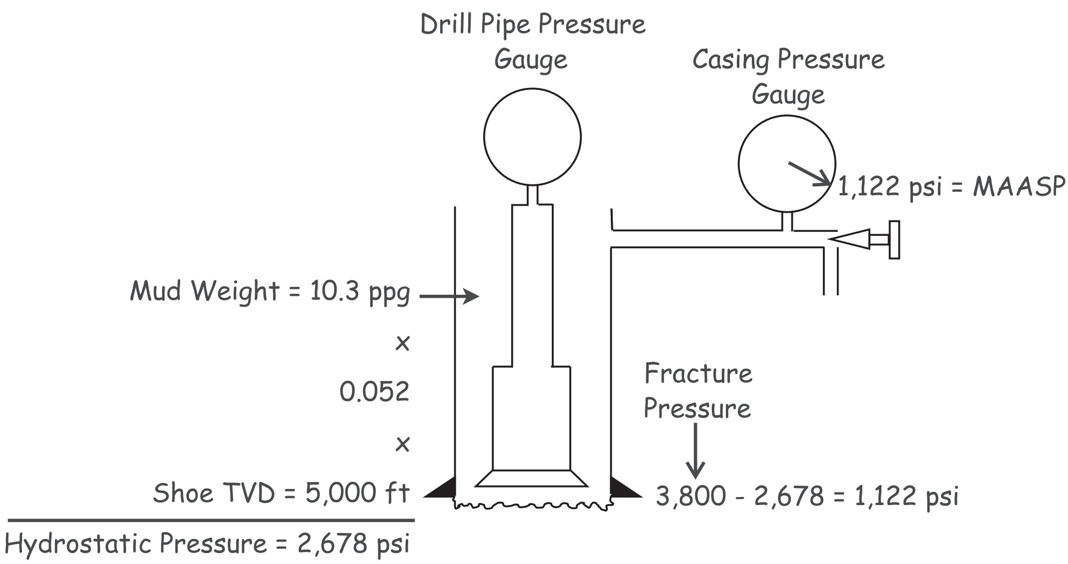
This spare pressure is the pressure you could apply to the shoe, in addition to the mud hydrostatic pressure which is already acting there, without breaking down the formation at the shoe.

Where is the pressure likely to be applied from?

During a well control situation you have pressures in the well. These can be seen on two gauges at surface. Pressure in the drill string can be seen on the drill pipe pressure gauge. Pressure in the annulus can be seen on the casing pressure gauge. It is pressure in the annulus that acts down on the shoe.

The spare pressure is known as the maximum allowable annular surface pressure, or MAASP. It is the maximum pressure you can have on the casing gauge (the annulus gauge) at surface in the early stages of a kill operation that will not exceed the fracture pressure at the shoe.

For the well opposite MAASP is 1,122 psi.



It is important not to exceed MAASP in the early stages of a kill operation. You will learn much more about MAASP when you attend well control school. For now you just need to know where the value for MAASP comes from.

The well you have been working on has the following data:

Shoe TVD = 5,000 ft; Fracture pressure = 3,800 psi
Maximum Mud Wt. = 14.6 ppg; Current Mud Wt. = 10.3 ppg

and MAASP was worked out as 1,122psi

MAASP is the maximum pressure that can be applied to the casing shoe in addition to the mud hydrostatic that is already acting there.

MAASP was worked out by subtracting the mud hydrostatic pressure from fracture pressure. Fracture pressure is said to be the hydrostatic pressure exerted by maximum mud weight. (OK it will be a little bit less, but this is better than being a little bit too high.)

Fracture Pressure could be worked as follows:

$$\text{Fracture Pressure} = 14.6 \times 0.052 \times 5{,}000 = \underline{3{,}796\ \text{psi}}$$

This is less that the fracture pressure above and is simply due to the fact that maximum mud weight has actually been rounded down to 14.6 ppg from 14.61538461 ppg. This is acceptable for calculation purposes.

Shoe hydrostatic pressure is:

$$\text{Shoe Hydrostatic Pressure} = 10.3 \times 0.052 \times 5{,}000 = \underline{2{,}678\ \text{psi}}$$

MAASP could be worked out as follows:

$$\text{MAASP} = \text{Fracture Pressure} - \text{Shoe Hydrostatic Pressure}$$

$$= 3{,}796 - 2{,}678 = \underline{1{,}118\ \text{psi}}$$

This value for MAASP is 4 psi less than you calculated earlier but again is due to the fact that maximum mud weight was rounded down.

There is a formula that can be used to quickly calculate MAASP:

MAASP (psi) = (Max Mud Wt.(ppg) - Current Mud Wt.(ppg)) x 0.052 x Shoe TVD (ft)

MAASP (psi) = (14.6 - 10.3) x 0.052 x 5000

= 4.3 x 0.052 x 5,000

= <u>1,118 psi</u>

You have worked out the difference between the two mud weights, then done a hydrostatic pressure calculation with it.

MAASP needs to be recalculated every time you change your mud weight.

Why?

Every time you change the mud weight you will change the hydrostatic pressure acting on the shoe. If the fracture pressure does not change, but the amount of hydrostatic pressure you are exerting does change, then the extra pressure you can apply must also change.

As you increase the mud weight then MAASP will decrease. Using the example above what is MAASP if the current mud weight is now 12 ppg?

MAASP (psi) = (14.6 - 12) x 0.052 x 5000 = 2.6 x 0.052 x 5,000 = <u>676 psi</u>

Work out MAASP in these:

1) Max mud wt = 17.4 ppg; current mud wt = 13.6 ppg; shoe TVD = 8,850 ft

2) Current mud wt = 9.3 ppg; max mud wt = 14.7 ppg; shoe TVD = 6,340 ft

3) Shoe TVD = 7,300 ft; current mud wt = 10.8 ppg; fracture gradient = 0.78 psi/ft

4) Fracture pressure = 8,100 psi; current mud wt = 11.4 ppg; shoe TVD = 10,200 ft

ANSWERS

MAASP (psi) = (Max Mud Wt.(ppg) - Current Mud Wt.(ppg)) x 0.052 x Shoe TVD (ft)

---

1) MAASP (psi) = (17.4 - 13.6) x 0.052 x 8,850

= 3.8 x 0.052 x 8,850

= <u>1,749 psi</u>

---

2) MAASP (psi) = (14.7 - 9.3) x 0.052 x 6,340

= 5.4 x 0.052 x 6,340

= <u>1,780 psi</u>

---

3) Fracture gradient converts to maximum mud weight:

Max Mud Weight (ppg) = Fracture Gradient (psi/ft) ÷ 0.052

= 0.78 ÷ 0.052 = <u>15 ppg</u>

MAASP (psi) = (15 - 10.8) x 0.052 x 7,300

= 4.2 x 0.052 x 7,300

= <u>1,594 psi</u>

4) Once again there are several ways of working this one out.

You could work out the fracture gradient and, from that, maximum mud weight. This will allow you then to use the MAASP formula:

Fracture Gradient = Fracture Pressure ÷ Shoe TVD

= 8,100 ÷ 10,200 = 0.7941 psi/ft

Max Mud Weight (ppg) = Fracture Gradient (psi/ft) ÷ 0.052

= 0.7941 ÷ 0.052 = 15.2 ppg

MAASP (psi) = (15.2 - 11.4) x 0.052 x 10,200

= 3.8 x 0.052 x 10,200 = 2,015 psi

MAASP can also be worked out by subtracting the mud hydrostatic pressure from fracture pressure. This is perhaps a quicker way for this particular question.

Shoe Hydrostatic Pressure = 11.4 x 0.052 x 10,200 = 6,047 psi

MAASP = Fracture Pressure - Shoe Hydrostatic Pressure

= 8,100 - 6,047 = 2,053 psi

NOTE that in this example there is a difference of 38 psi between the two answers. This is due to the fact that maximum mud weight is rounded down.

The second answer is the more mathematically accurate as it has been calculated directly from fracture pressure. The first answer is how MAASP is usually calculated in the field and gives you a much greater safety margin.

Both are acceptable for calculation purposes and the correct answer will fall within this range.

TRIPPING PRESSURE CALCULATIONS

In chapter two you looked at what happens when you trip pipe in and out the hole. As you run in the hole fluid is displaced out into the trip tank. The volume displaced must equal the volume you run in the hole. On a trip out the hole you remove volume from the hole and this volume is replaced by mud from the trip tank. Accurate trip monitoring is important in both cases.

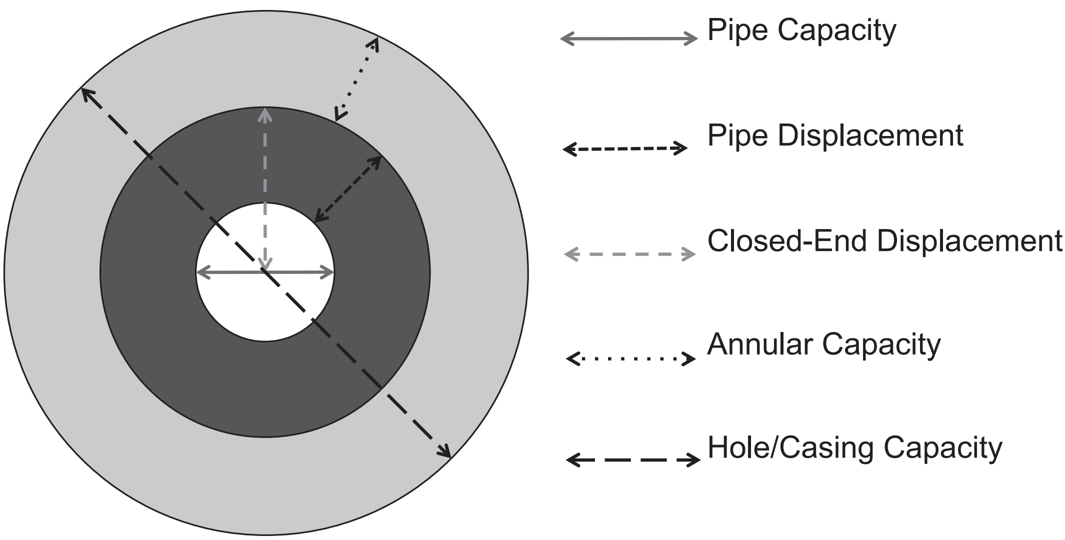
If you did not keep the hole full on a trip out, then the mud level would drop. This would cause a drop in hydrostatic pressure. If you lose 100 ft of 10 ppg mud then you will lose:

$$10 \times 0.052 \times 100 = 52 \text{ psi}$$

Now this may not seem much, however, if you lost 1,000 ft of mud, you would lose 520 psi of hydrostatic pressure on the bottom of the hole. This could cause problems.

So what happens if you trip out without filling the hole?

You will remember this cross-section of a well showing capacities from chapter two.

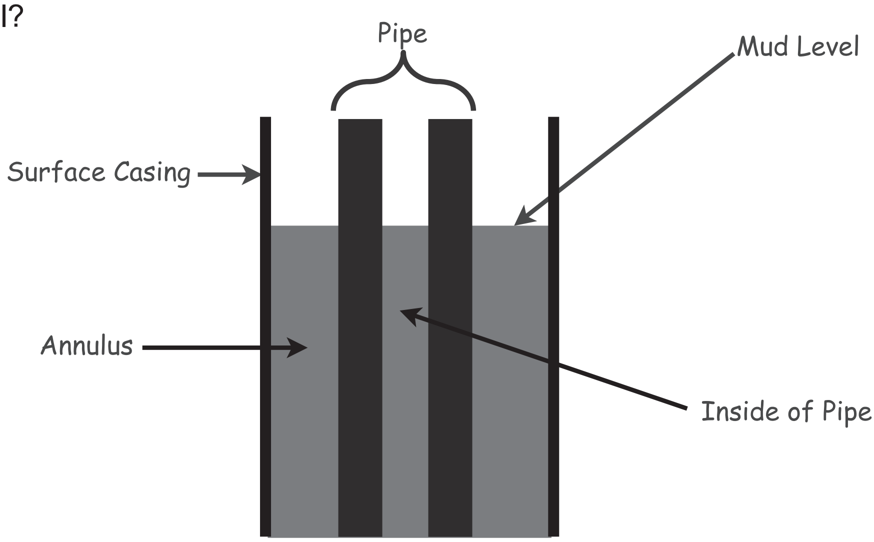


If you trip out dry then you are only removing pipe from the hole. The mud inside the pipe u-tubes back into the hole.

If you remove 10 x 90 ft stands, with a pipe displacement of 0.00764 bbl/ft, you will have removed:

$$10 \times 90 \times 0.00764 = \underline{6.876 \text{ bbl}}$$ of steel from the hole.

If you did not fill the hole with mud, then the volume of mud in the hole would fall by 6.876 bbl. The mud level will also fall by this amount. If you are tripping dry then the mud level will fall in the annulus and inside the pipe. How far does the mud level fall?



For the example above, pipe capacity is 0.01776 bbl/ft and the annular capacity is 0.0508 bbl/ft. This means the total capacity where the level has dropped is:

$$0.01776 + 0.0508 = \underline{0.06856 \text{ bbl/ft}}$$

You can now divide the volume you have lost by the capacity to get the level drop in feet:

$$6.876 \div 0.06856 = \underline{100 \text{ ft}}$$

If you have 10 ppg mud in the hole you will lose 52 psi of hydrostatic pressure.

If you trip the same 10 stands wet what will happen?

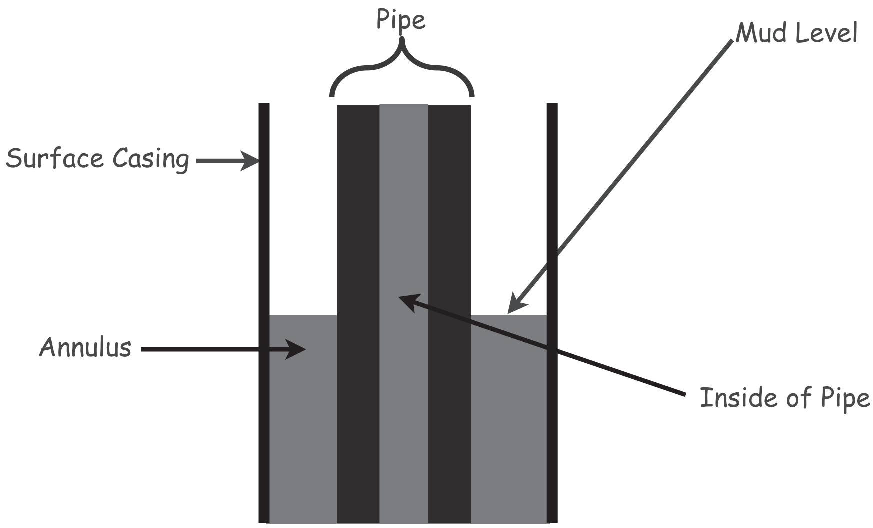
For a start, the volume you remove from the hole will be different. This time you are removing closed-end displacement:

$$0.01776 + 0.00764 = \underline{0.0254 \text{ bbl/ft}}$$

The volume removed will be:

$$10 \times 90 \times 0.0254 = \underline{22.86 \text{ bbl}}$$

The mud level drop will only be in the annulus this time:



If the annular capacity is 0.0508 bbl/ft then the level drop will be:

$$22.86 \text{ bbl} \div 0.0508 = \underline{450 \text{ ft}}$$

With 10 ppg mud in the hole this will result in a drop in hydrostatic pressure of:

$$10 \times 0.052 \times 450 = \underline{234 \text{ psi}}$$

A bit more significant this time!

The good news is that there are a couple of formulas to help you work out what happens if you trip out without filling the hole.

The other good news is that given you have mastered the order of doing a calculation these formulas do not scare you in the least.

$$\text{Pressure Drop per Foot Tripping Dry Pipe (psi)} = \frac{(\text{Mud Wt. (ppg)} \times 0.052) \times \text{Pipe Displacement (bbl/ft)}}{\text{Casing Capacity (bbl/ft)} - \text{Pipe Displacement (bbl/ft)}}$$

$$\text{Pressure Drop per Foot Tripping Wet Pipe (psi)} = \frac{(\text{Mud Wt. (ppg)} \times 0.052) \times \text{Closed-End Displacement (bbl/ft)}}{\text{Casing Capacity (bbl/ft)} - \text{Closed-End Displacement (bbl/ft)}}$$

These formulas work out the pressure drop per foot for tripping pipe. In order to get the total pressure drop you must multiply the answer by the amount of pipe tripped.

If casing capacity was 0.0762 bbl/ft in the wet trip example opposite you get:

$$\text{Pressure Drop per Foot Tripping Wet Pipe (psi)} = \frac{(\text{Mud Wt. (ppg)} \times 0.052) \times \text{Closed-End Displacement (bbl/ft)}}{\text{Casing Capacity (bbl/ft)} - \text{Closed-End Displacement (bbl/ft)}}$$

$$= \frac{(10 \times 0.052) \times 0.0254}{0.0762 - 0.0254} = \frac{0.013208}{0.0508} = \underline{0.26 \text{ psi}}$$

Multiply this by the 900 ft tripped out to give a reduction in pressure of:

$$0.26 \times 900 = \underline{234 \text{ psi}}$$

These calculations are about the trickiest you are likely to come across. Treat them as problem solving exercises.

First of all, find the correct formula. Next, make sure you have all the data you need for the formula. Put the numbers into the formula in the correct place, making sure you include any brackets. Finally, do the calculation following the correct mathematical rules.

What is the reduction in bottom hole pressure if you trip 18 x 93 foot stands out the hole, dry, without hole fill?

Mud Weight = 11.4 ppg; Closed-End displacement = 0.02017 bbl/ft
Casing capacity = 0.0787 bbl/ft Pipe capacity = 0.01287 bbl/ft

Find the formula and check you have the data you need.

$$\text{Pressure Drop per Foot Tripping Dry Pipe (psi)} = \frac{(\text{Mud Wt. (ppg)} \times 0.052) \times \text{Pipe Displacement (bbl/ft)}}{\text{Casing Capacity (bbl/ft)} - \text{Pipe Displacement (bbl/ft)}}$$

You don't have pipe displacement. It needs to be worked out first:

$$\text{Pipe displacement} = \text{Closed-End displacement} - \text{Pipe capacity}$$

$$= 0.02017 - 0.01287 = \underline{0.0073 \text{ bbl/ft}}$$

You now have all the data you need for the formula:

$$\text{Pressure Drop per Foot Tripping Dry Pipe (psi)} = \frac{(11.4 \times 0.052) \times 0.0073}{0.0787 - 0.0073} = \frac{0.00432744}{0.0714} = \underline{0.0606 \text{ psi}}$$

Finally, you need to multiply the answer to the formula, by the length of pipe pulled out the hole, to answer the question:

$$0.0606 \times 93 \times 18 = \underline{101 \text{ psi}}$$

It is possible to do this calculation using the memory button in your calculator. First you do the calculation below the line; store that answer in the memory; do the calculation above the line; divide that answer by the one in the memory; multiply that by the length of each stand and then by the amount of stands you have to get the final answer. Key strokes are:

0.0787 - 0.0073 = M+ C 11.4 x 0.052 x 0.0073 = ÷ MR = x 93 x 18 = <u>101 psi</u>

Follow it through on your calculator to see what happens. Carry on writing the calculations down in stages if you are more comfortable going that way.

Answer the following:

Data Set One:

Pipe Capacity = 0.01725 bbl/ft; Pipe Displacement = 0.0075 bbl/ft
Stand Length = 92 ft; Mud Wt. = 13.7 ppg; Casing Capacity = 0.0708 bbl/ft

Data Set Two:

Stand Length = 89 ft; Mud Wt. = 11.4 ppg; Casing Capacity = 0.1571 bbl/ft
Closed-End Displacement = 0.02477 bbl/ft; Pipe Capacity = 0.01887 bbl/ft

1) Using data set one, work out the reduction in bottom hole pressure if 14 stands are pulled dry, without hole fill.

2) Using data set two, work out the reduction in bottom hole pressure if 9 stands are pulled wet, without hole fill.

3) Using data set two, work out the reduction in bottom hole pressure if 18 stands are pulled dry, without hole fill.

4) Using data set one, work out the reduction in bottom hole pressure if 14 stands are pulled wet, without hole fill.

ANSWERS

1) $$\text{Pressure Drop per Foot Tripping Dry Pipe (psi)} = \frac{(\text{Mud Wt. (ppg)} \times 0.052) \times \text{Pipe Displacement (bbl/ft)}}{\text{Casing Capacity (bbl/ft)} - \text{Pipe Displacement (bbl/ft)}}$$

$$= \frac{(13.7 \times 0.052) \times 0.0075}{0.0708 - 0.0075}$$

$$= \frac{0.005343}{0.0633} = \underline{0.0844 \text{ psi}}$$

Reduction in Bottom Hole Pressure = 0.0844 x 92 x 14 = <u>109 psi</u>

---

2) $$\text{Pressure Drop per Foot Tripping Wet Pipe (psi)} = \frac{(\text{Mud Wt. (ppg)} \times 0.052) \times \text{Closed-End Displacement (bbl/ft)}}{\text{Casing Capacity (bbl/ft)} - \text{Closed-End Displacement (bbl/ft)}}$$

$$= \frac{(11.4 \times 0.052) \times 0.02477}{0.1571 - 0.02477}$$

$$= \frac{0.014683656}{0.13233} = \underline{0.111 \text{ psi}}$$

Reduction in Bottom Hole Pressure = 0.111 x 89 x 9 = <u>89 psi</u>

3) $$\text{Pressure Drop per Foot Tripping Dry Pipe (psi)} = \frac{(\text{Mud Wt. (ppg)} \times 0.052) \times \text{Pipe Displacement (bbl/ft)}}{\text{Casing Capacity (bbl/ft)} - \text{Pipe Displacement (bbl/ft)}}$$

Pipe displacement = Closed-End displacement - Pipe capacity

= 0.02477 - 0.01887 = <u>0.0059 bbl/ft</u>

$$\text{Pressure Drop per Foot Tripping Dry Pipe (psi)} = \frac{(11.4 \times 0.052) \times 0.0059}{0.1571 - 0.0059}$$

$$= \frac{0.00349752}{0.1512} = \underline{0.02313 \text{ psi}}$$

Reduction in Bottom Hole Pressure = 0.02313 x 89 x 18 = <u>37 psi</u>

---

4) $$\text{Pressure Drop per Foot Tripping Wet Pipe (psi)} = \frac{(\text{Mud Wt. (ppg)} \times 0.052) \times \text{Closed-End Displacement (bbl/ft)}}{\text{Casing Capacity (bbl/ft)} - \text{Closed-End Displacement (bbl/ft)}}$$

Closed-End displacement = Pipe displacement + Pipe capacity

= 0.0075 + 0.01725 = <u>0.02475 bbl/ft</u>

$$\text{Pressure Drop per Foot Tripping Wet Pipe (psi)} = \frac{(13.7 \times 0.052) \times 0.02475}{0.0708 - 0.02475}$$

$$= \frac{0.017503668}{0.04605} = \underline{0.38 \text{ psi}}$$

Reduction in Bottom Hole Pressure = 0.38 x 92 x 14 = <u>489 psi</u>

This chapter has been about pressure, so it seems appropriate to put you under a bit of pressure with the test. Actually, if you have worked through this chapter honestly, you should feel no pressure whatsoever when tackling this test.

The topics covered included:

Pressure gradient
Hydrostatic pressure
Variations on the basic formula
Circulating pressure loss
Bottom hole circulating pressure
ECD
Change of pump speed
Change of mud weight
Leak-off tests & fracture pressure
Fracture gradient & maximum mud weight
MAASP
Wet & dry tripping calculations

By way of revision, take some time just now to have a look over the complete chapter once more. Pay particular attention to any topics you are not sure about.

You have used several formulas through this section, many of which may be useful in the final exam. There are some shown on the opposite page.

You may wish to write them down on a separate sheet of loose paper so you can have them to view as you work through the test. This will save you flicking forwards and backwards to look at formulas.

Good luck - not that luck comes into it.

FORMULAS

Pressure Gradient (psi/ft) = Mud Weight (ppg) x 0.052

Mud Weight (ppg) = Pressure Gradient (psi/ft) ÷ 0.052

Hydrostatic Pressure (psi) = Mud Weight (ppg) x 0.052 x TVD (ft)

Mud Weight (ppg) = Pressure (psi) ÷ TVD (ft) ÷ 0.052

TVD (ft) = Pressure (psi) ÷ Mud Weight (ppg) ÷ 0.052

BHCP (psi) = Hydrostatic Pressure in the Annulus (psi) + APL (psi)

$$\text{ECD (ppg)} = \frac{\text{APL (psi)}}{\text{TVD (ft)} \times 0.052} + \text{Current Mud Weight (ppg)}$$

$$\text{New Pressure at New Pump Speed (psi)} = \left[\frac{\text{New Pump Speed (spm)}}{\text{Old Pump Speed (spm)}}\right]^2 \times \text{Pressure at Old Pump Speed (psi)}$$

$$\text{New Pressure with New Mud Weight (psi)} = \frac{\text{New Mud Weight (ppg)}}{\text{Old Mud Weight (ppg)}} \times \text{Pressure with Old Mud Weight (psi)}$$

Max Mud Wt. (ppg) = (LOT Pressure (psi) ÷ Shoe TVD (ft) ÷ 0.052) + Test Mud Wt. (ppg)

MAASP (psi) = (Max Mud Wt.(ppg) - Current Mud Wt.(ppg)) x 0.052 x Shoe TVD (ft)

$$\text{Pressure Drop per Foot Tripping Dry Pipe (psi)} = \frac{(\text{Mud Wt. (ppg)} \times 0.052) \times \text{Pipe Displacement (bbl/ft)}}{\text{Casing Capacity (bbl/ft)} - \text{Pipe Displacement (bbl/ft)}}$$

$$\text{Pressure Drop per Foot Tripping Wet Pipe (psi)} = \frac{(\text{Mud Wt. (ppg)} \times 0.052) \times \text{Closed-End Displacement (bbl/ft)}}{\text{Casing Capacity (bbl/ft)} - \text{Closed-End Displacement (bbl/ft)}}$$

CHAPTER TEST

WELL DATA

Current Mud Wt. = 11.5 ppg

Well TVD = 12,720 ft

Pump Speed = 110 spm

Shoe TVD = 7,300 ft

Test Mud Wt. = 10.8 ppg

Fracture Pressure = 5,690 psi

APL = 370 psi

Stand Length = 91 ft

Pipe closed-end displacement = 0.02022 bbl/ft

Pipe capacity = 0.01422 bbl/ft

Casing capacity = 0.034 bbl/ft

Answer the following using the well data opposite along with the information given in each question. Pressure should be rounded to the nearest psi, mud weights, except maximum mud weight, to 2 decimal places, pressure gradient to 4 decimal places and depth to the nearest foot.

1) Calculate the surface leak-off test pressure and also the maximum mud weight.

2) What is the pressure gradient of the current mud?

3) What is the current hydrostatic pressure at the bottom of the hole?

4) What pressure is acting on the bottom of the hole when you are circulating at the given pump rate?

5) What is ECD at the given pump rate?

6) What will be the reduction in bottom hole pressure if 20 stands are tripped out the hole, dry, without hole fill?

7) The current pump pressure is 3,850 psi. The mud weight is to be increased to 11.9 ppg while the pumps will be cut back to 95 spm. What will the pump pressure be once both changes have been made?

8) What will the new MAASP be once the mud weight has been increased to 11.9 ppg?

9) The mud weight has been changed again. The hydrostatic pressure is now 8,268 psi. Well TVD is still the same. What is the new mud weight?

10) The well has been drilled deeper and bottom hole hydrostatic pressure is now 9,477 psi. The mud weight has changed again. It is now 13.5 ppg. What is the true vertical depth of the well?

11) With 13.5 ppg mud in the hole, what will be the reduction in bottom hole pressure if 5 stands are tripped out of the hole, wet, without hole fill?

ANSWERS

1) Calculate the surface leak-off test pressure and also the maximum mud weight.

Fracture Pressure = Shoe Hydrostatic Pressure at Test + LOT Pressure

therefore:

LOT Pressure = Fracture Pressure - Shoe Hydrostatic Pressure at Test

Shoe Hydrostatic Pressure = 10.8 x 0.052 x 7,300 = <u>4,100 psi</u>

LOT Pressure (psi) = 5,690 - 4,100 = <u>1,590 psi</u>

Max Mud Wt. (ppg) = (LOT Pressure (psi) ÷ Shoe TVD (ft) ÷ 0.052) + Test Mud Wt. (ppg)

= (1,590 ÷ 7,300 ÷ 0.052) + 10.8 = <u>14.9 ppg</u>

---

2) What is the pressure gradient of the current mud?

Pressure Gradient (psi/ft) = Mud Weight (ppg) x 0.052

= 11.5 x 0.052 = <u>0.598 psi/ft</u>

---

3) What is the current hydrostatic pressure at the bottom of the hole?

Hydrostatic Pressure (psi) = Mud Weight (ppg) x 0.052 x TVD (ft)

= 11.5 x 0.052 x 12,720

= <u>7,607 psi</u>

4) What pressure is acting on the bottom of the hole when you are circulating at the given pump rate?

$$BHCP\ (psi) = \text{Hydrostatic Pressure in the Annulus}\ (psi) + APL\ (psi)$$

You have just worked out hydrostatic pressure in the previous question.

$$BHCP\ (psi) = 7{,}607 + 370 = \underline{7{,}977\ psi}$$

---

5) What is ECD at the given pump rate?

$$ECD\ (ppg) = \frac{APL\ (psi)}{TVD\ (ft) \times 0.052} + \text{Current Mud Weight}\ (ppg)$$

$$= \frac{370}{12{,}720 \times 0.052} + 11.5$$

$$= \frac{370}{661.44} + 11.5$$

$$= 0.559385582 + 11.5$$

$$= \underline{12.06\ ppg}$$

6) What will be the reduction in bottom hole pressure if 20 stands are tripped out the hole, dry, without hole fill?

$$\text{Pressure Drop per Foot Tripping Dry Pipe (psi)} = \frac{(\text{Mud Wt. (ppg)} \times 0.052) \times \text{Pipe Displacement (bbl/ft)}}{\text{Casing Capacity (bbl/ft)} - \text{Pipe Displacement (bbl/ft)}}$$

Pipe displacement= Closed-end displacement - Pipe capacity

= 0.02022 - 0.01422 = 0.006 bbl/ft

$$\text{Pressure Drop per Foot Tripping Dry Pipe (psi)} = \frac{(11.5 \times 0.052) \times 0.006}{0.034 - 0.006}$$

$$= \frac{0.003588}{0.028} = 0.128 \text{ psi}$$

Reduction in Bottom Hole Pressure = 0.128 x 91 x 20 = 233 psi

---

7) The current pump pressure is 3,850 psi. The mud weight is to be increased to 11.9 ppg while the pumps will be cut back to 95 spm. What will the pump pressure be once both changes have been made?

$$\text{New Pressure with New Mud Weight (psi)} = \frac{\text{New Mud Weight (ppg)}}{\text{Old Mud Weight (ppg)}} \times \text{Pressure with Old Mud Weight (psi)}$$

$$= \frac{11.9}{11.5} \times 3{,}850 = 1.034782608 \times 3{,}850 = 3{,}984 \text{ psi}$$

$$\text{New Pressure at New Pump Speed (psi)} = \left[\frac{\text{New Pump Speed (spm)}}{\text{Old Pump Speed (spm)}}\right]^2 \times \text{Pressure at Old Pump Speed (psi)}$$

$$= \left[\frac{95}{110}\right]^2 \times 3{,}984$$

$$= 0.863636363^2 \text{ X } 3{,}984 = .745867767 \text{ X } 3{,}984 = 2{,}972 \text{ (psi)}$$

The new pump pressure will be 2,972 psi

8) What will the new MAASP be once the mud weight has been increased to 11.9 ppg?

MAASP(psi) = (Max Mud Wt.(ppg) - Current Mud Wt.(ppg)) x 0.052 x Shoe TVD(ft)

You worked out maximum mud weight in Question 1 as 14.9 ppg

MAASP (psi) = (14.9 - 11.9) x 0.052 x 7,300 = 1,139 psi

---

9) The mud weight has been changed again. The hydrostatic pressure is now 8,268 psi. Well TVD is still the same. What is the new mud weight?

Mud Weight (ppg) = Pressure (psi) ÷ TVD (ft) ÷ 0.052

= 8,268 ÷ 12,720 ÷ 0.052

= 12.5 ppg

---

10) The well has been drilled deeper and bottom hole hydrostatic pressure is now 9,477 psi. The mud weight has changed again. It is now 13.5 ppg. What is the true vertical depth of the well?

TVD (ft) = Pressure (psi) ÷ Mud Weight (ppg) ÷ 0.052

= 9,477 ÷ 13.5 ÷ 0.052

= 13,500 ft

11) With 13.5 ppg mud in the hole, what will be the reduction in bottom hole pressure if 5 stands are tripped out of the hole, wet, without hole fill?

$$\text{Pressure Drop per Foot Tripping Wet Pipe (psi)} = \frac{(\text{Mud Wt. (ppg)} \times 0.052) \times \text{Closed-End Displacement (bbl/ft)}}{\text{Casing Capacity (bbl/ft)} - \text{Closed-End Displacement (bbl/ft)}}$$

$$= \frac{(13.5 \times 0.052) \times 0.02022}{0.034 - 0.02022}$$

$$= \frac{0.01419444}{0.01378}$$

$$= \underline{1.03 \text{ psi}}$$

Reduction in Bottom Hole Pressure = 1.03 x 91 x 5 = <u>469 psi</u>

FINAL SCORE

Use the marking table below to score how well you did in the chapter test.

Question	Answer	Correct or Incorrect	Value	Your Score
1 LOT pressure	1,590 psi		4	
1 max mud weight	14.9 ppg		2	
2	0.598 psi/ft		2	
3	7,607 psi		2	
4	7,977 psi		3	
5	12.06 ppg		3	
6	233 psi		4	
7	2,972 psi		4	
8	1,139 psi		2	
9	12.5 ppg		2	
10	13,500 ft		2	
11	469 psi		4	
Total Score Available = 34 Points		Your Total Score =		

Your Score = ____________ ÷ 34 x 100 = [%]

Round to the nearest whole percentage. If you scored 70% or above then you passed.

LAST WORD

So you made it to the end of the third chapter - well done again.

You now only have one chapter to go to complete the whole book which is even better news.

This chapter has focused on some of the basics of pressure.

There are other pressure calculations that have not been covered in this chapter but now you understand how pressure works you will pick these up pretty quickly when you need to.

The final chapter will continue with pressure calculations but this time it will look at those specifically used in well control.

There will be many familiar terms in the next chapter along with some new ones.

Once you have completed the final chapter you will be ready for any calculations you may encounter at well control school. You may not have covered them but you will be able to deal with them, that's for sure.

Take the pressure off for a bit and have a break before starting the next chapter - but don't wait too long though.

No mud loggers were insulted in the making of this chapter at all - what a wasted opportunity!

NOTES

CHAPTER 4
WELL CONTROL

At last we get into the well control calculations!! As always things build up slowly, one point is fully covered before moving on to the next. Topics this time include:

- Formation pressure
- Balance, overbalance & underbalance
- Formation pressure - again
- Kill mud weight
- ICP
- FCP
- Influx height
- Influx gradient
- Kill sheet pressure calculations

As ever there is a chapter test at the end to allow you to check your own understanding.

D. Cormack, *An Introduction to Well Control Calculations for Drilling Operations*, DOI 10.1007/978-3-319-63190-5_4

DON'T PANIC

You've made it to the final chapter in this book. Well done.

You have already mastered calculations, and learned something about volume and pressure. This chapter is going to link bits of what you already know into well control.

Pressure plays a big part in well control, so much of what you cover will be reasonably familiar.

This chapter is laid out exactly as the others were. There are a number of lessons, which make up a subject. Each lesson will be no more than two pages long, which means you always have a complete lesson to view. You never need to turn the page to complete a learning point.

There are worked examples - go through them using your own calculator to see how they work. There are a number of calculations for you to try yourself. Do them all.

Fully worked out answers are given for each question - make sure you try the questions before looking at the answers.

When working out calculations, remember to write them down, ensuring everything is clearly written and identified. Write down all the stages of a calculation, including the final answer, with its correct unit.

By the time you have completed this chapter, and done so honestly, you will be ready for well control school. Hey, you may even be able to help out some of the toolpushers with their calculations! You will only be able to do this though, if you:

Take your time. **Do not skip anything.** **Read every word.**

Do every calculation.

A QUICK REFRESHER

Before you start on well control calculations it is worth quickly refreshing what you learned in chapter three. The subjects covered included:

Pressure gradient
Hydrostatic pressure
Circulating pressures & ECD
Change of pump speed & mud weight
Leak off, MAASP & maximum mud weight
Wet & dry tripping calculations

Warm up time - answer the following:

$$\text{ECD (ppg)} = \frac{\text{APL (psi)}}{\text{TVD (ft)} \times 0.052} + \text{Current Mud Weight (ppg)}$$

$$\text{MAASP (psi)} = (\text{Max Mud Wt.(ppg)} - \text{Current Mud Wt.(ppg)}) \times 0.052 \times \text{Shoe TVD (ft)}$$

$$\text{Pressure Drop per Foot Tripping Dry Pipe (psi)} = \frac{(\text{Mud Wt. (ppg)} \times 0.052) \times \text{Pipe Displacement (bbl/ft)}}{\text{Casing Capacity (bbl/ft)} - \text{Pipe Displacement (bbl/ft)}}$$

WELL DATA

Pipe displacement = 0.0071 bbl/ft; Casing capacity = 0.0787 bbl/ft;
Current mud weight = 11.6 ppg; Max Mud Weight = 16.2 ppg;
APL = 280 psi; Shoe TVD = 7,945 ft; TVD = 11,330 ft

1) What will be the reduction in bottom hole pressure if 22 x 93 ft stands are tripped out the hole dry without hole fill?

2) What is MAASP?

3) What is ECD?

ANSWERS

1) $$\text{Pressure Drop per Foot Tripping Dry Pipe (psi)} = \frac{(\text{Mud Wt. (ppg)} \times 0.052) \times \text{Pipe Displacement (bbl/ft)}}{\text{Casing Capacity (bbl/ft)} - \text{Pipe Displacement (bbl/ft)}}$$

$$= \frac{(11.6 \times 0.052) \times 0.0071}{0.0787 - 0.0071}$$

$$= \frac{0.00428272}{0.0716}$$

$$= \underline{0.0598 \text{ psi}}$$

Reduction in Bottom Hole Pressure = 0.0598 x 93 x 22 = <u>122 psi</u>

---

2) MAASP (psi) = (Max Mud Wt.(ppg) - Current Mud Wt.(ppg)) x 0.052 x Shoe TVD (ft)

= (16.2 - 11.6) x 0.052 x 7,945

= <u>1,900 psi</u>

---

3) $$\text{ECD (ppg)} = \frac{\text{APL (psi)}}{\text{TVD (ft)} \times 0.052} + \text{Current Mud Weight (ppg)}$$

$$= \frac{280}{11{,}330 \times 0.052} + 11.6$$

$$= \frac{280}{589.16} + 11.6$$

= 0.475252902 + 11.6

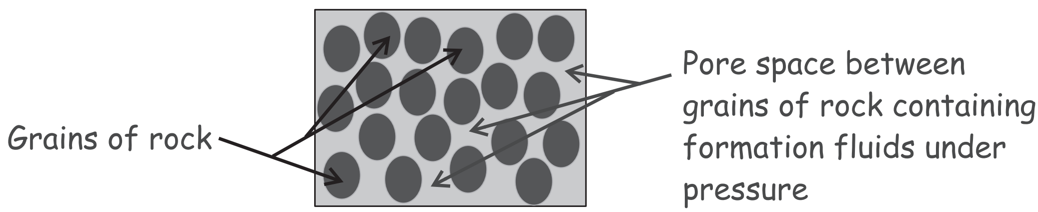
= <u>12.08 ppg</u>

FORMATION PRESSURE

This chapter is about well control calculations - not well control. Well control school is the best place to learn about well control. However, some background information will be helpful so, throughout this chapter, there will be bits and pieces that are not strictly calculations.

Well control is all about being in control of the well. You want to ensure that the well does not flow until you are ready for it to flow.

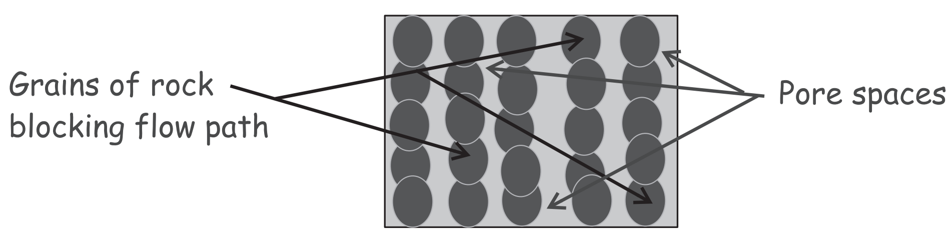
Formation fluids (gas is classified as a fluid here) are contained, under pressure, within the pore spaces of the rocks you are drilling through. This is illustrated in the picture below.



The main factor creating this pressure in the formation is the weight of everything above, pushing down and compressing it. This process is known as compaction.

Formation pressure is the pressure of the fluid contained within the pore spaces of the rock.

Another factor that affects whether or not the well flows is the permeability of the formation. Permeability is how easily the pore spaces will allow formation fluid to flow. The formation shown above is very permeable and will allow the easy flow of fluids. The formation below is fairly impermeable and fluids will not be able to flow easily.



In this chapter, assume that all formations are permeable.

Formation fluid is water containing salts. Formation pressure is the pressure of the fluid in a formation being drilled. Anticipated formation pressure for wells you drill will be gathered from a number of sources, such as seismic surveys or offset data. Formation pressure is usually expressed as a pressure gradient - psi/ft.

Normal formation pressure gradient varies around the world but is generally taken to be 0.465 psi/ft. What is this as a ppg mud weight?

Mud Weight (ppg) = Pressure Gradient (psi/ft) ÷ 0.052

= 0.465 ÷ 0.052 = <u>8.94 ppg</u>

Normal formation pressure is assumed to be the pressure exerted by a column of formation fluid.

What would the formation pressure be in a 10,000 ft TVD well that was normally pressured?

Pressure (psi) = Pressure Gradient (psi/ft) x TVD (ft)

= 0.465 x 10,000 = <u>4,650 psi</u>

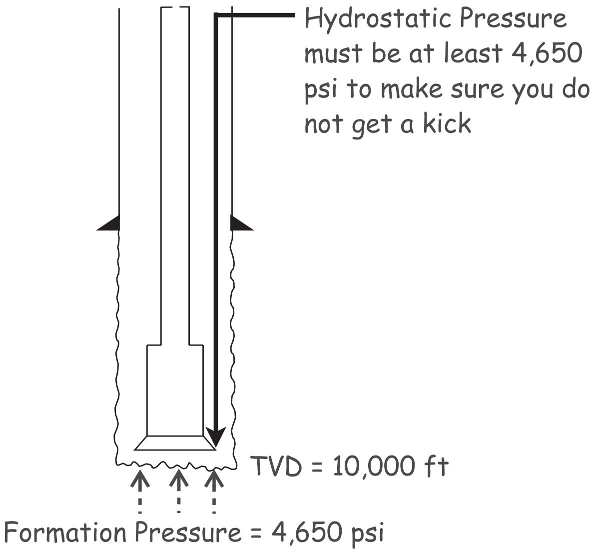
Formation pressure in this well is 4,650 psi. As you drill, this pressure will try to force formation fluid into the well and up to surface.

The unwanted entry of formation fluid into the well is known as a kick. If this kick comes to surface, and escapes uncontrolled, it is known as a blowout. Kicks and blowouts should be avoided at all times. You need to be in control of the well.

Hydrostatic pressure is used to prevent kicks. You need to make sure that the hydrostatic pressure of the mud you have in the hole is equal to, or greater than, formation pressure.

What mud weight would you need to have in the well above to equal formation pressure?

BALANCE



$$\text{Mud Weight (ppg)} = \text{Pressure (psi)} \div \text{TVD (ft)} \div 0.052$$

$$= 4{,}650 \div 10{,}000 \div 0.052 = \underline{8.94 \text{ ppg}}$$

The same weight as the pressure gradient converted to - no surprises there.

If you had this fluid in the well it would be in balance. Formation pressure and hydrostatic pressure would be equal.

Answer the following:

1) What is formation pressure?
Formation pressure gradient = 0.53 psi/ft; TVD = 11,740 ft.

2) What is formation pressure?
Formation pressure gradient = 0.475 psi/ft; TVD = 9,330 ft;

3) What mud weight balances formation pressure?
Formation pressure = 3,744 psi; TVD = 7,500 ft

4) What mud weight balances formation pressure?
Formation pressure = 6,552 psi TVD = 13,125 ft

ANSWERS

1) Pressure (psi) = Pressure Gradient (psi/ft) x TVD (ft)

= 0.53 x 11,740 = <u>6,222 psi</u>

---

2) Pressure (psi) = 0.475 x 9,330 = <u>4,432 psi</u>

---

3) Mud Weight (ppg) = Pressure (psi) ÷ TVD (ft) ÷ 0.052

= 3,744 ÷ 7,500 ÷ 0.052 = <u>9.6 ppg</u>

---

4) Mud Weight (ppg) = 6,552 ÷ 13,125 ÷ 0.052 = <u>9.6 ppg</u>

OVERBALANCE

In questions 3 & 4 above, you worked out balance mud weight. The hydrostatic pressure exerted by the column of mud exactly equals formation pressure.

The pressure pushing down is the same as the pressure pushing up.

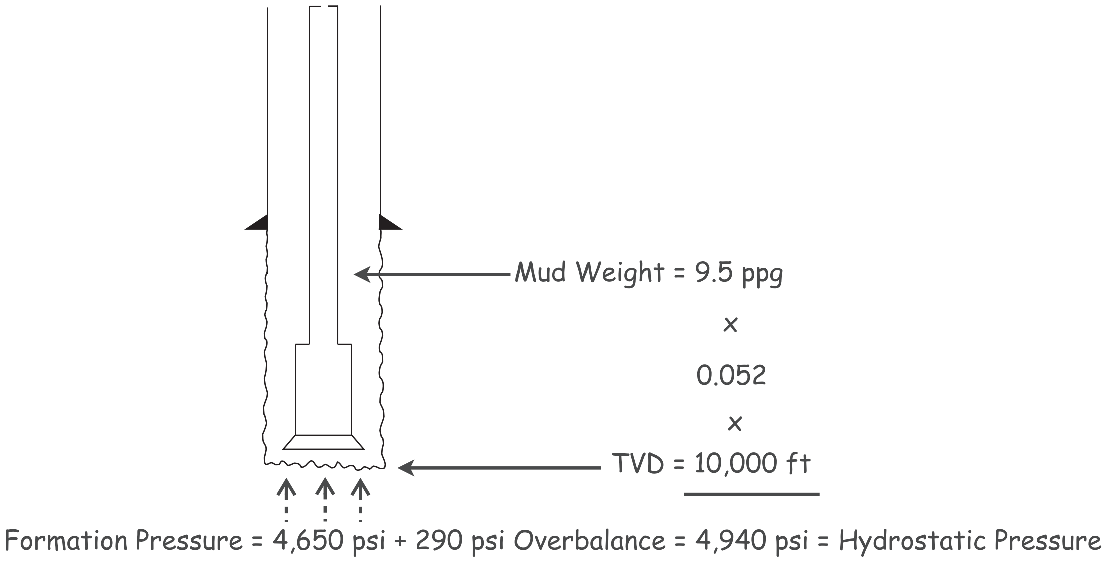
Most wells are drilled in a state of overbalance where hydrostatic pressure is greater than formation pressure.

Formation pressure is 4,650 psi at 10,000 ft TVD. What mud weight would you need in the hole to give you a 290 psi overbalance?

The total pressure you need is 4,650 + 290 = <u>4,940 psi</u> so:

Mud Weight (ppg) = Pressure (psi) ÷ TVD (ft) ÷ 0.052

= 4,940 ÷ 10,000 ÷ 0.052 = <u>9.5 ppg</u>



For normal drilling operations, mud weights will not just balance formation pressure but will also include some overbalance. This will ensure that bottom hole pressure is greater than formation pressure at all times.

When mud hydrostatic pressure is equal to, or greater than, formation pressure you have primary well control.

Answer the following.

1) What mud weight is required to give an overbalance of 250 psi?

Formation pressure gradient = 0.7176 psi/ft; TVD = 12,660 ft

2) What is formation pressure if you have an overbalance of 325 psi?

Mud weight = 11.8 ppg; TVD = 11,750 ft

3) Well TVD is 8,250 ft. How much overbalance is there?

Mud weight = 10.8 ppg; Formation pressure gradient = 0.524 psi/ft

4) Mud weight is 10.2 ppg. Do you have primary well control?

Formation pressure gradient = 0.5252 psi/ft TVD = 7,455 ft

ANSWERS

1) Formation Pressure (psi) = Pressure Gradient (psi/ft) x TVD (ft)

= 0.7176 x 12,660 = 9,085 psi

Hydrostatic pressure needs to be:

Formation Pressure + Overbalance

= 9,085 + 250 = 9,335 psi

therefore:

Mud Weight (ppg) = Pressure (psi) ÷ TVD (ft) ÷ 0.052

= 9,335 ÷ 12,660 ÷ 0.052 = 14.18 ppg

In the field this would be 14.2 ppg. For calculation purposes continue to work out mud weights to two decimal places unless told otherwise.

---

2) Hydrostatic Pressure (psi) = Mud Weight (ppg) x 0.052 x TVD (ft)

= 11.8 x 0.052 x 11,750

= 7,210 psi

Formation pressure (psi) = Hydrostatic pressure (psi) - Overbalance (psi)

= 7,210 - 325

= 6,885 psi

3) Formation pressure (psi) = Hydrostatic pressure (psi) - Overbalance (psi)

which rearranges to give:

Overbalance (psi) = Hydrostatic pressure (psi) - Formation pressure (psi)

Hydrostatic Pressure (psi) = 10.8 x 0.052 x 8,250 = 4,633 psi

Formation Pressure (psi) = 0.524 x 8,250 = 4,323 psi

Overbalance (psi)= 4,633 - 4,323 = 310 psi

---

4) Hydrostatic Pressure (psi) = 10.2 x 0.052 x 7,455 = 3,954 psi

Formation Pressure (psi) = 0.5252 x 7,455 = 3,915 psi

Hydrostatic pressure is greater than formation pressure by 39 psi. You have overbalance so yes, you do have primary well control.

A QUICK SUMMARY

To calculate formation pressure multiply formation pressure gradient by TVD.

A balance mud weight exerts a hydrostatic pressure that will equal formation pressure. You can calculate this directly from the formation pressure gradient - simply divide by 0.052, or from formation pressure and TVD, using a variation of the hydrostatic pressure formula.

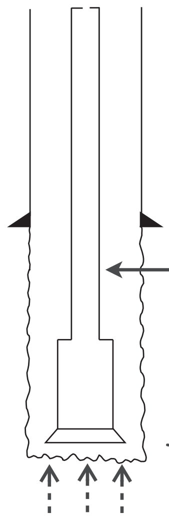
You will normally have some overbalance built into your mud weight. This ensures hydrostatic pressure is greater than formation pressure.

When hydrostatic pressure is equal to, or greater than, formation pressure you have primary well control.

You should maintain primary well control at all times during drilling and associated operations.

UNDERBALANCE

Do you have primary well control below?



Formation pressure works out at:

$$\text{Formation Pressure (psi)} = 0.57 \times 10{,}000 = \underline{5{,}700 \text{ psi}}$$

Hydrostatic pressure works out at:

$$\text{Hydrostatic Pressure (psi)} = 10 \times 0.052 \times 10{,}000 = \underline{5{,}200 \text{ psi}}$$

Hydrostatic pressure of 5,200 psi is less than (under) the balance value of 5,700 psi, by 500 psi. The well is in a state of underbalance.

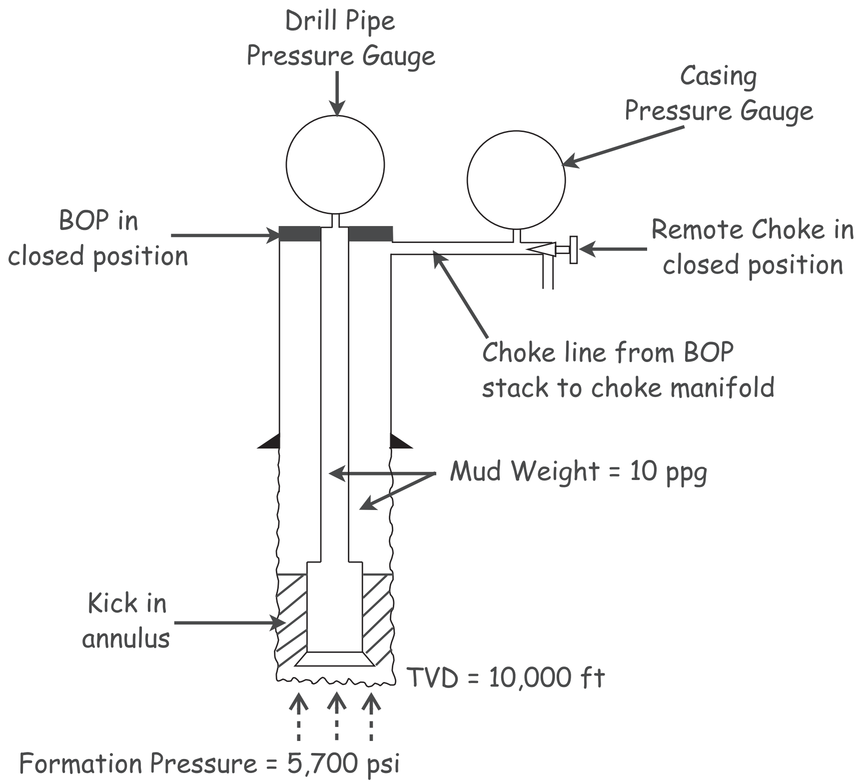
If the formation is permeable, then the well will flow and you will get a kick.

We will assume the kick comes into the annulus and moves upwards. This will displace mud out at surface. The driller should recognise this excess flow as a kick, and close the well in using the BOPs.

Once the BOPs have been closed, there will be no further flow of mud out of the well. Pressure will build up. This build up can be monitored on two gauges at surface - the drill pipe pressure gauge and the casing pressure gauge.

The drill pipe pressure gauge measures the pressure acting up the inside of the drill string and the casing pressure gauge measures the pressure acting up the inside of the annulus.

At some point the pressures will stabilise. These stabilised, shut in pressures are given a number of different names. In this book they will be called Shut In Drill Pipe Pressure (SIDPP) and Shut In Casing Pressure (SICP) respectively.

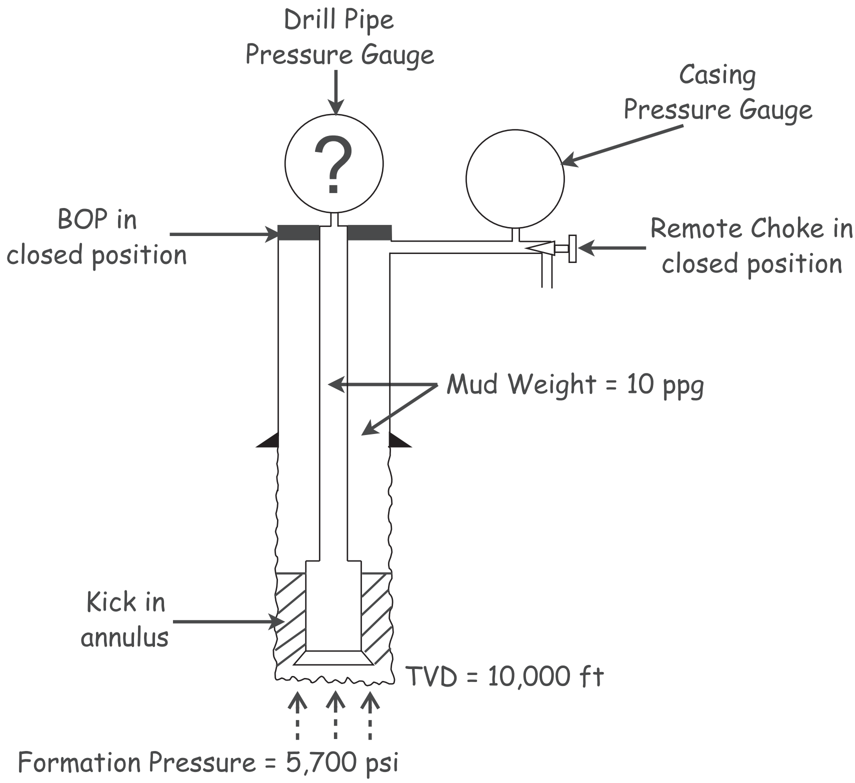


The picture above shows the well in a shut in position. This well and kick will be used as you work through many of the remaining subjects in this section.

Assume that there is no float installed in the drill string. This means the drill pipe pressure gauge will be open to pressure through the bit. Assume the bit is on bottom, the kick is all in the annulus and also on bottom.

FORMATION PRESSURE - AGAIN

The well has been shut in on a kick and the pressures have stabilised. What will SIDPP be equal to?



Formation pressure is pushing up the drill string with 5,700 psi of pressure. What is acting down the drill string? A clean column of 10 ppg mud. This gives a hydrostatic pressure of:

$$\text{Hydrostatic Pressure (psi)} = 10 \times 0.052 \times 10{,}000 = \underline{5{,}200 \text{ psi}}$$

If there is 5,700 psi pushing up the drill string, and 5,200 psi pushing back down the drill string, then the pressure on the gauge at surface will read the difference. In this case 500 psi.

For this kick, SIDPP is 500 psi. You will be able to read this on the drill pipe pressure gauge, once the pressures have stabilised.

In most kick situations, you will not know formation pressure ahead of time. If you did, you should not have taken the kick!

Once you have taken a kick, however, you will be able to read SIDPP on the drill pipe pressure gauge. You will know the well TVD, and the mud weight you have in the hole. From those you will be able to work out the hydrostatic pressure acting down the drill string.

Formation pressure is the sum of SIDPP and string hydrostatic pressure - just add them together to get formation pressure. Check that on the well opposite:

Formation Pressure (psi) = Hydrostatic Pressure in Drill String (psi) + SIDPP (psi)

= 5,200 + 500 = 5,700 psi

In a kick situation SIDPP is used to calculate formation pressure.

Answer the following, to the nearest psi:

1) What is formation pressure? TVD = 13,560 ft; SIDPP = 385 psi; Mud Weight = 11.5 ppg

2) What is formation pressure? Mud Weight = 9.9 ppg; TVD = 8,125 ft; SIDPP = 610 psi

3) What is formation pressure? Mud Gradient = 0.6968 psi/ft; SIDPP = 460 psi; TVD = 14,820 ft

4) What is SIDPP? TVD = 9,455 ft; Mud Weight = 10.3 ppg; Formation Pressure Gradient = 0.5564 psi/ft

5) What is SIDPP? TVD = 15,670 ft; Mud Weight = 14.8 ppg; Formation Pressure Gradient = 0.811 psi/ft

ANSWERS

1) Formation Pressure (psi) = Hydrostatic Pressure in Drill String (psi) + SIDPP (psi)

Hydrostatic Pressure (psi) = 11.5 x 0.052 x 13,560 = 8,109 psi

Formation Pressure (psi) = 8,109 + 385 = 8,494 psi

---

2) Hydrostatic Pressure (psi) = 9.9 x 0.052 x 8,125 = 4,183 psi

Formation Pressure (psi) = 4,183 + 610 = 4,793 psi

---

3) Hydrostatic Pressure (psi) = Pressure Gradient (psi/ft) x TVD (ft)

= 0.6968 x 14,820 = 10,327 psi

Formation Pressure (psi) = 10,327 + 460 = 10,787 psi

---

4) Formation Pressure (psi) = Hydrostatic Pressure in Drill String (psi) + SIDPP (psi)

therefore:

SIDPP (psi) = Formation Pressure (psi) - Hydrostatic Pressure in Drill String (psi)

Formation Pressure (psi) = Pressure Gradient (psi/ft) x Depth (ft)

= 0.5564 x 9,455 = 5,261 psi

Hydrostatic Pressure (psi) = 10.3 x 0.052 x 9,455 = 5,064 psi

SIDPP (psi) = 5,261 - 5,064 = 197 psi

5) SIDPP (psi) = Formation Pressure (psi) - Hydrostatic Pressure in Drill String (psi)

Formation Pressure (psi) = 0.811 x 15,670 = <u>12,708 psi</u>

Hydrostatic Pressure (psi) = 14.8 x 0.052 x 15,670 = <u>12,060 psi</u>

SIDPP (psi) = 12,708 - 12,060 = <u>648 psi</u>

This question could be tackled another way.

SIDPP is the difference between formation pressure and the hydrostatic pressure in the drill string. TVD is the same for both of those calculations.

If you convert the mud weight to a gradient, you could subtract it from the formation pressure gradient to work out the difference between the two gradients.

Multiply this difference in gradients by TVD and you will get the difference between formation pressure and hydrostatic pressure - which is SIDPP.

Mud Gradient (psi/ft) = Mud Weight (ppg) x 0.052

= 14.8 x 0.052 = 0.7696 psi/ft

Difference between gradients = 0.811 - 0.7696 = <u>0.0414 psi/ft</u>

Difference in pressure (psi) = 0.0414 x 15,670 = <u>649 psi</u>

One psi of difference. In a hole in the ground full of mud this is no difference at all.

The same thing works for question 4. Try it yourself. Answer over the page.

ANSWER

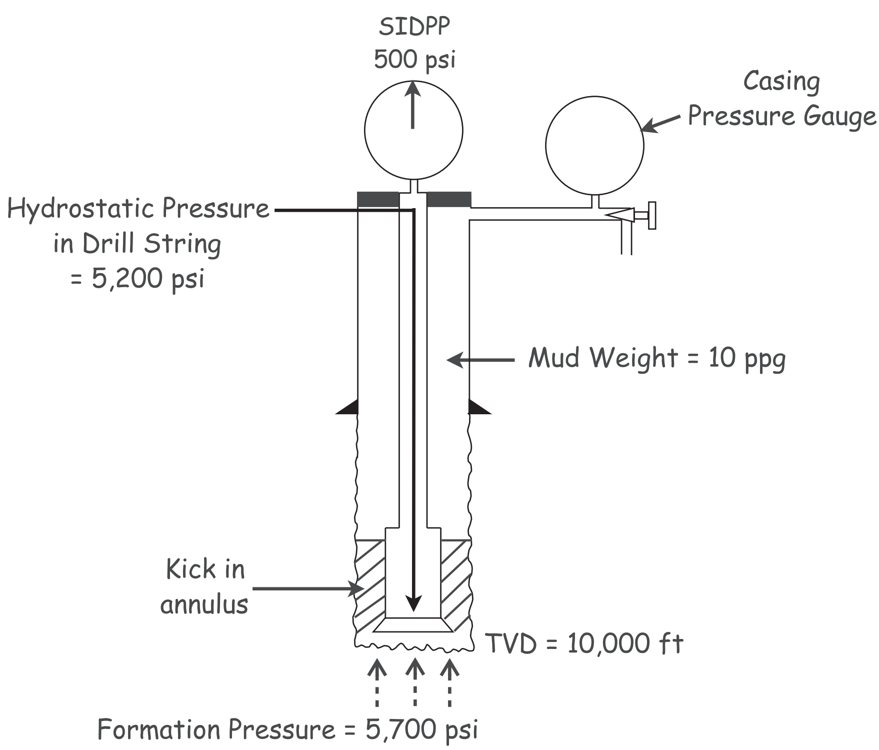
4) Mud Gradient (psi/ft) = 10.3 x 0.052 = 0.5356 psi/ft

Difference between gradients = 0.5564 - 0.5356 = 0.0208 psi/ft

Difference in pressure (psi) = 0.0208 x 9,455 = 197 psi

This time it works out to the same answer. For most pressure calculations there will be more than one way to get an answer. The main difference will be whether you use pressure gradient or mud weight. There might be a slight variation in the answers. Any variation is usually down to mathematical rounding.

OK, back to the well. You have shut in on a kick and the pressures have stabilised. The current situation is shown below.



KILL MUD WEIGHT

You have taken a kick because you lost primary well control. The hydrostatic pressure in the well was less than formation pressure. In order to regain primary well control you will need to increase the hydrostatic pressure in the well. The only way you can do this is by increasing the mud weight.

This new mud weight is known as kill mud weight. The formula for calculating kill mud weight is:

Kill Mud Weight (ppg) = (SIDPP (psi) ÷ TVD (ft) ÷ 0.052) + Current Mud Weight (ppg)

= (500 ÷ 10,000 ÷ 0.052) + 10 = 10.96 ppg

If kill mud weight is correct then it will restore primary well control. Try it.

Hydrostatic Pressure (psi) = 10.96 x 0.052 x 10,000 = 5,699 psi

One psi out - does it make any difference? Usually, no it does not. In this case yes it does - it still leaves you under balance.

When calculating kill mud weight, the normal mathematical rounding rules do not apply. It is standard practice to **round up** kill mud weight to one decimal place.

In the example above 10.96 ppg becomes 11 ppg. Hydrostatically this gives:

Hydrostatic Pressure (psi) = 11 x 0.052 x 10,000 = 5,720 psi

This is greater than formation pressure and will restore primary well control.

Round up the following to one decimal place.

1) 12.459 ppg

2) 13.123 ppg

3) 15.801 ppg

4) 16.901 ppg

ANSWERS

1) 12.459 - the first decimal is 4 so it becomes 5, giving you 12.5 ppg

---

2) 13.123 - the first decimal is 1 so it becomes 2, giving you 13.2 ppg

---

3) 15.801 - the first decimal is 8 so it becomes 9, giving you 15.9 ppg

---

4) 16.901 - the first decimal is 9 so the mud weight rounds to 17 ppg

Individual companies and well control schools may have different rules for kill mud weight, but throughout this book, when calculating kill mud, you should **round up** your answer to one decimal place.

There is a mathematical version of the kill mud weight formula. You used it in book one. It will give the same answer as the calculator friendly version.

$$\text{Kill Mud Weight (ppg)} = \frac{\text{SIDPP (psi)}}{\text{Well TVD (ft)} \times 0.052} + \text{Current Mud Weight (ppg)}$$

$$= \frac{500}{10{,}000 \times 0.052} + 10$$

$$= \frac{500}{520} + 10$$

$$= 0.961538461 + 10 = 10.96 = \underline{11\text{ ppg}}$$

There is yet another way to calculate kill mud weight. Can you figure it out how, before you look at the next page?

You can use the variation of the hydrostatic pressure that works out mud weight.

Mud Weight (ppg)= Pressure (psi) ÷ TVD (ft) ÷ 0.052

The pressure value you must use is formation pressure, and the answer you get will be kill mud weight. Formation pressure was 5,700 psi therefore:

Mud Weight (ppg) = 5,700 ÷ 10,000 ÷ 0.052 = 10.96 = 11 ppg

As with many of the pressure related calculations, there are a few ways to calculate kill mud weight. Whichever way you work it out, you will be using a variation of the basic hydrostatic pressure formula.

Have a look at the standard kill mud weight formula.

Kill Mud Weight (ppg) = (SIDPP (psi) ÷ TVD (ft) ÷ 0.052) + Current Mud Weight (ppg)

You divide psi, by feet, by 0.052, and then add ppg, to get an answer in ppg.

Pretty much the same thing you are doing in the mud weight formula on this page. In the kill mud weight formula the first thing you do is convert SIDPP to a pressure gradient, and then to a mud weight. This is the increase in mud weight. You then add that to the mud weight that is already in the hole to get kill mud weight.

Calculate kill mud weight for the following:

1) TVD = 11,245 ft; Current Mud Weight = 11.3 ppg; SIDPP = 260 psi

2) Current Mud Weight = 12.8 ppg; SIDPP = 580 psi; TVD = 13,770 ft

3) SIDPP = 440 psi; TVD = 9,885 ft; Mud gradient = 0.5668 psi/ft

4) Formation pressure gradient = 0.73 psi/ft; TVD = 15,415 ft; Current mud weight = 13.7 ppg

ANSWERS

1) Kill Mud Weight (ppg) = (SIDPP (psi) ÷ TVD (ft) ÷ 0.052) + Current Mud Weight (ppg)

= (260 ÷ 11,245 ÷ 0.052) + 11.3

= 11.74

= 11.8 ppg

---

2) Kill Mud Weight (ppg) = (580 ÷ 13,770 ÷ 0.052) + 12.8

= 13.61

= 13.7 ppg

---

3) Kill Mud Weight (ppg) = (SIDPP (psi) ÷ TVD (ft) ÷ 0.052) + Current Mud Weight (ppg)

Mud Weight (ppg) = Pressure Gradient (psi/ft) ÷ 0.052

= 0.5668 ÷ 0.052

= 10.9 ppg

Kill Mud Weight (ppg) = (440 ÷ 9,885 ÷ 0.052) + 10.9

= 11.76

= 11.8 ppg

4) Hmmmmmm - several ways to tackle this one.

SIDPP is the difference between formation pressure and hydrostatic pressure:

Formation Pressure (psi) = 0.73 x 15,415 = 11,253 psi

Hydrostatic Pressure (psi) = 13.7 x 0.052 x 15,415 = 10,982 psi

SIDPP (psi) = 11,253 - 10,982 = 271 psi

Kill Mud Weight (ppg) = (271 ÷ 15,415 ÷ 0.052) + 13.7

= 14.04 = 14.1 ppg

Alternatively, you could convert formation pressure to a mud weight:

Mud Weight (ppg) = 11,253 ÷ 15,415 ÷ 0.052 = 14.04 = 14.1 ppg

Alternatively, you could just convert the formation pressure gradient to a mud weight:

Mud Weight (ppg) = Pressure Gradient (psi/ft) ÷ 0.052

= 0.73 ÷ 0.052 = 14.04 = 14.1 ppg

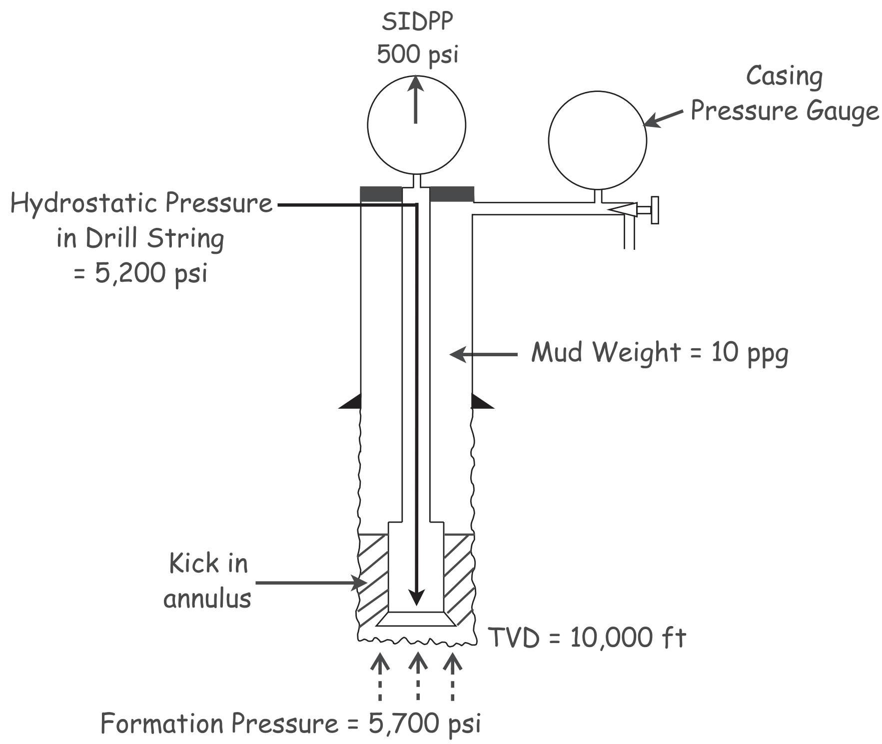
Either method gives you the same final answer for kill mud weight.

The deeper you understand the principles of pressure, and how the different units relate to each other, the more options you have for solving calculation problems.

However, you can always fall back on a formula - so **DON'T PANIC**.

ICP

The current situation is:



Kill mud weight has been worked out as 11 ppg. You have to circulate this mud round the well to regain primary well control. You also need to get rid of the kick from the annulus.

Bottom hole pressure must be held constant throughout the kill. It must be equal to, or greater than, formation pressure. In the real world you will almost certainly take a safety margin. This will ensure bottom hole pressure is above formation pressure. To keep the explanations clear in this book, no safety margin will be taken, bottom hole pressure will equal formation pressure.

There are two main methods for killing a well - the Driller's Method and the Wait & Weight Method. Both maintain a constant bottom hole pressure. This section is not about kill methods, it is about well control calculations. The calculations are common to both methods.

Kill mud will be circulated round the well at a slow pump rate. There are several reason for killing at a slow rate. The main reason is that it minimises the APL acting in the annulus, but it also gives the choke operator more time to think about, and react to, what is happening in the well during the kill.

There are two main circulating pressures during a kill and they are Initial Circulating Pressure (ICP) and Final Circulating Pressure (FCP).

Initial circulating pressure is the pressure you get when you first start circulating. It can be worked out using the formula:

ICP (psi) = SCR Pressure (psi) + SIDPP (psi)

What does this mean?

SCR Pressure is the Slow Circulating Rate Pressure for the pump speed chosen to kill the well. It is commonly called an SCR in the field.

SCRs are taken regularly during drilling operations to establish what the pump pressure will be, at a given well depth, with the mud weight currently in the hole, and, usually, for several different pump speeds.

Let's say you will kill the well at 30 spm, and that the SCR Pressure, with 10 ppg mud in the hole, was measured as 350 psi. This means that the pump puts out 350 psi of effort to circulate the mud round the well at 30 spm.

In a kick situation, you are shut in on pressure. Before the pump can get the mud moving, it will have to overcome this shut in pressure. The pressure it has to overcome is SIDPP.

At kill speed, the pump pressure will be the pressure required to move the mud, plus the pressure it has to overcome just to get the mud moving. Hence:

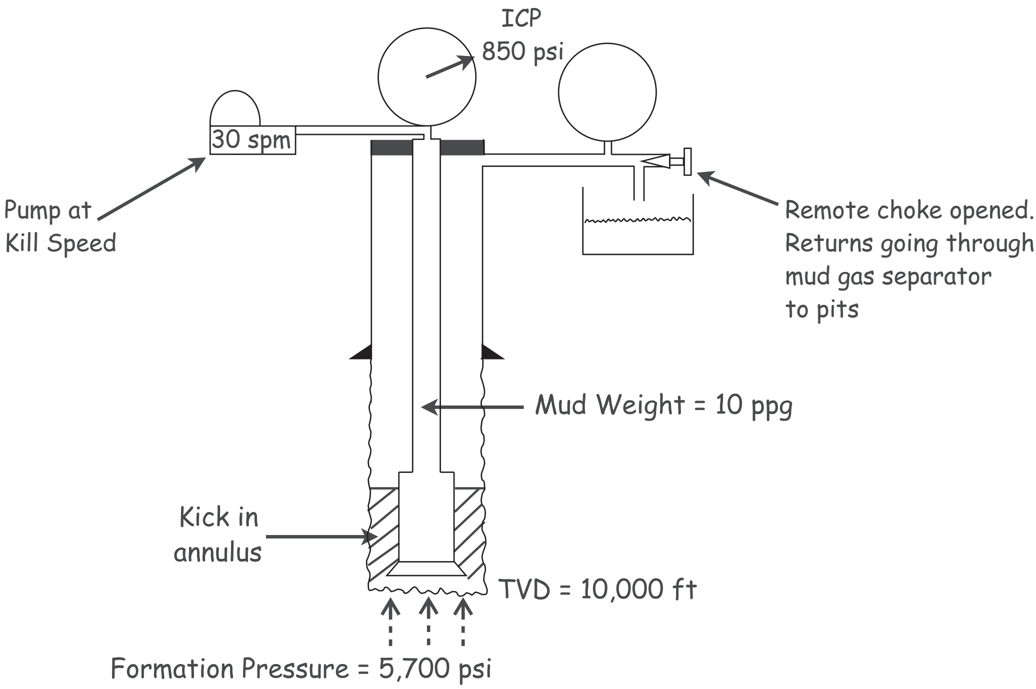
ICP (psi) = SCR Pressure (psi) + SIDPP (psi)

For the kick opposite this will be:

ICP (psi) = 350 + 500 = <u>850 psi</u>

FCP

Once the pump is at kill speed you will have ICP on the drill pipe gauge.



When you pump kill mud down the drill string, to the bit, you kill the drill string.

As you replace the old mud with kill mud, you restore primary well control in the drill string. By the time you have kill mud at the bit, the hydrostatic pressure in the drill string will be greater than formation pressure.

What would you read on the drill pipe pressure gauge if you were to shut the well in with kill mud at the bit?

Here, 10,000 ft of 11 ppg kill mud gives 5,720 psi of hydrostatic pressure. This is greater than formation pressure, which is 5,700 psi. If you were to shut the well in with kill mud at the bit, then the drill pipe pressure gauge would read zero. You have killed the string.

But have you killed the well?

No, you have not killed the well. You still have to circulate kill mud back up the annulus to fully kill the well.

When you pump kill mud down the drill string to the bit, drill pipe pressure will fall, as kill mud overcomes (or kills) the underbalance. By the time kill mud reaches the bit you will no longer have any underbalance. SIDPP would be zero if you were to shut the well in at this stage.

However, you don't normally shut the well, you continue with the kill operation.

Drill pipe pressure falls as kill mud is pumped to the bit. When kill mud reaches the bit, the drill pipe pressure gauge will read Final Circulating Pressure (FCP). FCP can be calculated using the formula:

$$\text{FCP (psi)} = \frac{\text{Kill Mud Weight (ppg)}}{\text{Current Mud Weight (ppg)}} \times \text{SCR Pressure (psi)}$$

You may recognise this as being the new pressure/new mud weight formula from chapter three.

It is the same formula - just different words! As you replace the old mud with kill mud, the pump pressure required to move the heavier mud will increase.

For the kill opposite, the measured SCR Pressure at 30 spm was 350 psi and kill mud is 11 ppg. FCP works out to:

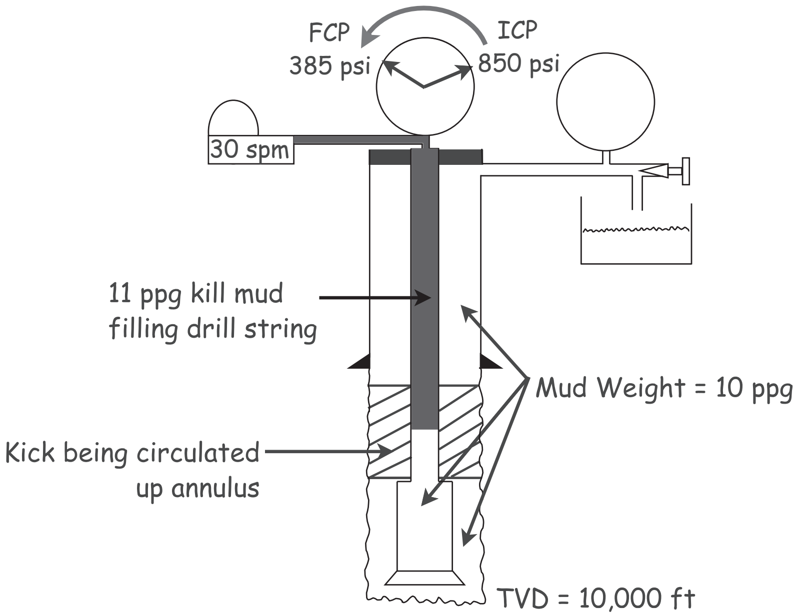
$$\text{FCP (psi)} = \frac{11}{10} \times 350$$

$$\text{FCP (psi)} = 1.1 \times 250 = \underline{385\ \text{psi}}$$

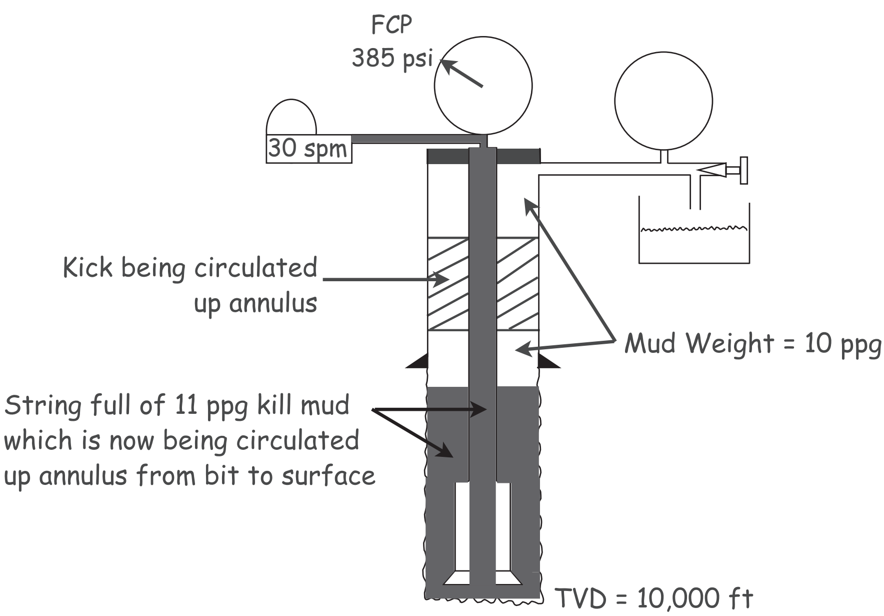
FCP should now be maintained on the drill pipe pressure gauge until you get kill mud back at surface. With the drill string and annulus both full of kill mud you have killed the whole well.

You will have restored primary well control.

As kill mud is pumped from surface to bit, drill pipe pressure falls from ICP to FCP.



As kill mud is pumped up the annulus, from bit to surface, drill pipe pressure is maintained at FCP.



The illustrations opposite show the kick still in the annulus as kill mud is circulated. The well is being killed using the Wait & Weight method. In the Driller's method, the kick will already be out of the well by the time you circulate kill mud.

The circulating pressures, however, will be the same regardless of which method you use to kill the well. You will learn more about kill methods on well control school.

Time for some questions.

$$\text{Formation Pressure (psi)} = \text{Hydrostatic Pressure in Drill String (psi)} + \text{SIDPP (psi)}$$

$$\text{Kill Mud Weight (ppg)} = (\text{SIDPP (psi)} \div \text{TVD (ft)} \div 0.052) + \text{Current Mud Weight (ppg)}$$

$$\text{ICP (psi)} = \text{SCR Pressure (psi)} + \text{SIDPP (psi)}$$

$$\text{FCP (psi)} = \frac{\text{Kill Mud Weight (ppg)}}{\text{Current Mud Weight (ppg)}} \times \text{SCR Pressure (psi)}$$

Well One Data:

TVD = 13,780 ft;	Current Mud Weight = 12.6 ppg;
SIDPP = 425 psi;	SCR Pressure = 390 psi

Well Two Data:

TVD = 9,210 ft;	Current Mud Weight = 10.2 ppg;
SIDPP = 375 psi;	SCR Pressure = 220 psi

Well Three Data:

TVD = 10,966 ft;	Current Mud Weight = 11.3 ppg;
SIDPP = 515 psi;	SCR Pressure = 310 psi

For each set of well data above calculate formation pressure, kill mud weight, ICP and FCP.

ANSWERS

Well One

String Hydrostatic Pressure (psi) = 12.6 x 0.052 x 13,780 = 9,029 psi

Formation Pressure (psi) = 9,029 + 425 = 9,454 psi

Kill Mud Weight (ppg) = (425 ÷ 13,780 ÷ 0.052) + 12.6 = 13.19 = 13.2 ppg

ICP (psi) = 390 + 425 = 815 psi

$$\text{FCP (psi)} = \frac{13.2}{12.6} \times 390 = 1.047619047 \times 390 = 409 \text{ psi}$$

Well Two

String Hydrostatic Pressure (psi) = 10.2 x 0.052 x 9,210 = 4,885 psi

Formation Pressure (psi) = 4,885 + 375 = 5,260 psi

Kill Mud Weight (ppg) = (375 ÷ 9,210 ÷ 0.052) + 10.2 = 10.98 = 11 ppg

ICP (psi) = 220 + 375 = 595 psi

$$\text{FCP (psi)} = \frac{11}{10.2} \times 220 = 1.078431372 \times 220 = 237 \text{ psi}$$

Well Three

$$\text{String Hydrostatic Pressure (psi)} = 11.3 \times 0.052 \times 10{,}966 = \underline{6{,}444 \text{ psi}}$$

$$\text{Formation Pressure (psi)} = 6{,}444 + 515 = \underline{6{,}959 \text{ psi}}$$

$$\text{Kill Mud Weight (ppg)} = (515 \div 10{,}966 \div 0.052) + 11.3 = 12.20 = \underline{12.3 \text{ ppg}}$$

Kill mud is one decimal place rounded up - apply no other thought process!

$$\text{ICP (psi)} = 310 + 515 = \underline{825 \text{ psi}}$$

$$\text{FCP (psi)} = \frac{12.3}{11.3} \times 310 = 1.088495575 \times 310 = \underline{337 \text{ psi}}$$

You could have done each of the kill mud weight calculations directly from formation pressure. They would give:

Well One: $\text{Kill Mud Weight (ppg)} = 9{,}454 \div 13{,}780 \div 0.052 = 13.19 = \underline{13.2 \text{ ppg}}$

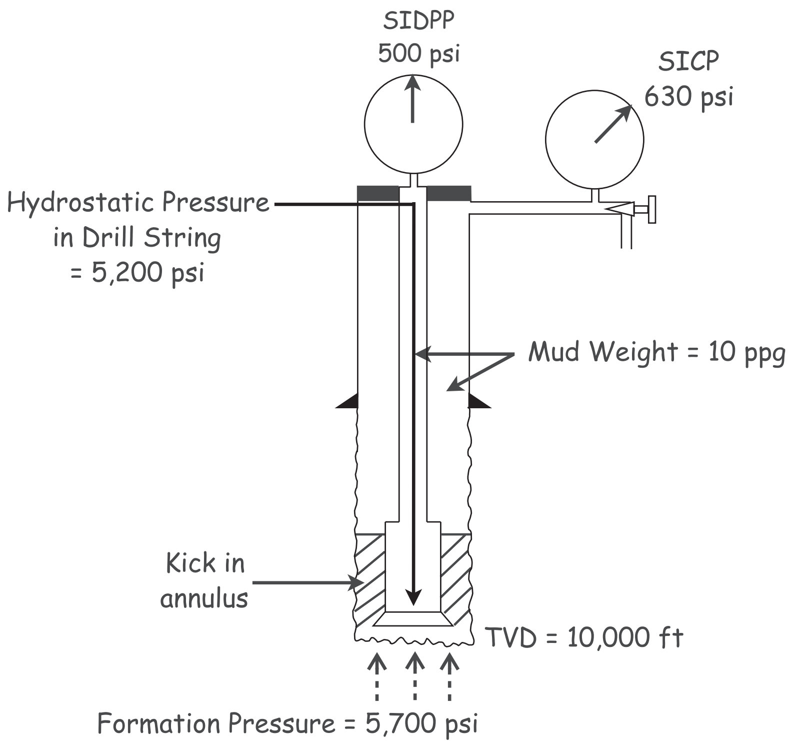
Well Two: $\text{Kill Mud Weight (ppg)} = 5{,}260 \div 9{,}210 \div 0.052 = 10.98 = \underline{11 \text{ ppg}}$

Well Three: $\text{Kill Mud Wt (ppg)} = 6{,}959 \div 10{,}966 \div 0.052 = 12.20 = \underline{12.3 \text{ ppg}}$

The four calculations you have just mastered are the four key well control calculations you will need in the field and on well control school.

INFLUX HEIGHT

When you shut in on a kick, the surface pressures will build up and, eventually, stabilise. In most cases SICP will be greater than SIDPP. Why is that?

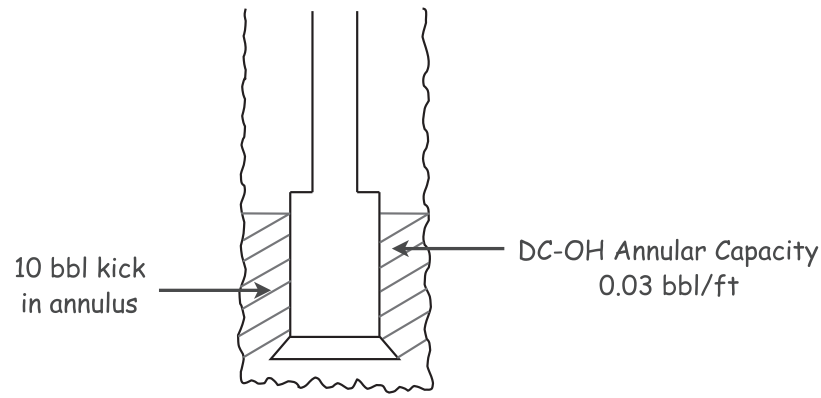


SICP is greater than SIDPP because the hydrostatic pressure in the annulus is less. In the drill string you have a clean column of mud from surface to bit. In the annulus you have a kick sitting on bottom. Kick fluids are generally lighter than mud. The hydrostatic pressure exerted by the gas and mud in the annulus will be less than the hydrostatic pressure of mud in the drill string.

Less hydrostatic pressure pushing down, against the same formation pressure pushing up, means a higher reading at surface.

So what is the situation in the annulus?

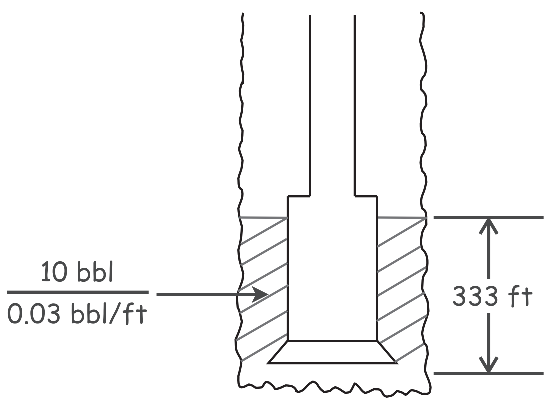
An assumption was made that the kick was on bottom. This means that the kick fills up the annulus from the bottom upwards. When you first took the kick there will have been a pit gain at surface. The volume of the pit gain will be the same as the volume of kick in the annulus. You will know your drill collar to open hole annular capacity.



You can work out the height of the kick (or influx) in the annulus. Every foot of annulus takes 0.03 bbl to fill it. How many feet will 10 bbl fill?

Influx Height (ft)= Kick Size (bbl) ÷ Annular Capacity (bbl/ft)

= 10 ÷ 0.03 = <u>333 ft</u>



There is 333 ft of kick at the bottom of this well in the annulus.

When a kick comes into the well it will take up space in the annulus. This space will equate to a height in the annulus. The height of the influx in a vertical well can be calculated using the formula:

Influx Height (ft) = Kick Size (bbl) ÷ Annular Capacity (bbl/ft)

What is the height of this influx?

Kick size = 30 bbl;	DC-OH capacity = 0.03 bbl/ft;	DC length = 600ft;
TVD = 13,486 ft;	DP-OH capacity = 0.045 bbl/ft;	DP length = 12,886 ft

The first thing to do is engage the brain!

Why is there so much information? It cannot be as simple as using the height of influx formula!! And it isn't.

First up, work out the volume to fill the DC-OH annulus.

Volume (bbl) = Capacity (bbl/ft) x Length (ft)

= 0.03 x 600 = <u>18 bbl</u>

This is less than size of the kick:

30 - 18 = <u>12 bbl</u>.

That means that the kick has filled to the top of the collars and 12 bbl is in the DP-OH Annulus.

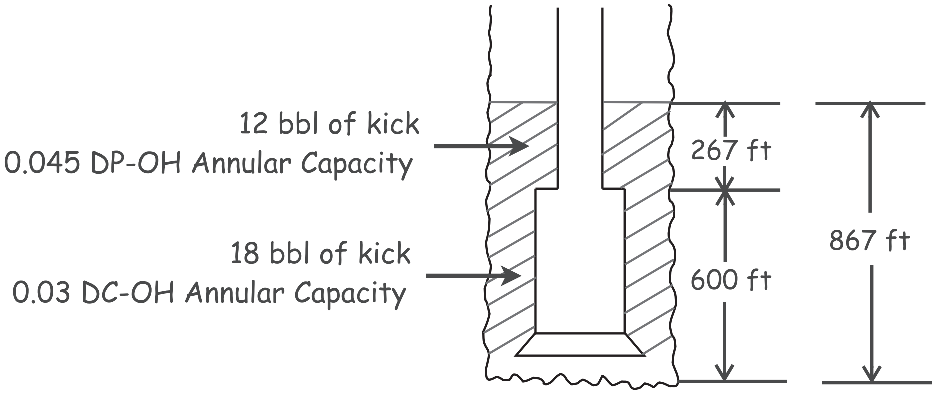
What is the height of the influx in this annulus?

Influx Height (ft) = 12 ÷ 0.045 = <u>267 ft</u>

Giving you a total height of influx of:

600 + 267 = <u>867 ft</u>

The picture opposite shows the situation for this kick.



The other information given is not relevant - figure out what you need and ignore the rest.

Calculate the influx height to the nearest foot in the following:

Influx Height (ft)= Kick Size (bbl) ÷ Annular Capacity (bbl/ft)

Volume (bbl) = Capacity (bbl/ft) x Length (ft)

1) Kick size = 25 bbl; DC-OH Capacity 0.0322 bbl/ft;
DP-OH Capacity = 0.0459 bbl/ft; DC Length = 900 ft

2) Kick size = 65 bbl; DC-OH Capacity 0.0836 bbl/ft;
DP-OH Capacity = 0.1215 bbl/ft; DC Length = 650 ft

3) Kick size = 50 bbl; DC-OH Capacity 0.2098 bbl/ft;
DP-OH Capacity = 0.2733 bbl/ft; DC Length = 300 ft

4) Kick size = 20 bbl; DC-OH Capacity 0.0226 bbl/ft;
DP-OH Capacity = 0.0505 bbl/ft; DC Length = 720 ft

ANSWERS

$$\text{Influx Height (ft)} = \text{Kick Size (bbl)} \div \text{Annular Capacity (bbl/ft)}$$

$$\text{Volume (bbl)} = \text{Capacity (bbl/ft)} \times \text{Length (ft)}$$

1) $$\text{Volume (bbl)} = 0.0322 \times 900 = \underline{28.98 \text{ bbl}}$$

This is more than the kick size so:

$$\text{Influx Height (ft)} = 25 \div 0.0322 = \underline{776 \text{ ft}}$$

---

2) $$\text{Volume (bbl)} = 0.0836 \times 650 = \underline{54.34 \text{ bbl}}$$

This is less than the kick size by:

$$65 - 54.34 = \underline{10.66 \text{ bbl}}$$

which sits in the DP-OH Annulus with a height of:

$$\text{Influx Height (ft)} = 10.66 \div 0.1215 = \underline{88 \text{ ft}}$$

giving a total height of influx of:

$$650 + 88 = \underline{738 \text{ ft}}$$

3) Volume (bbl) = 0.2098 x 300 = 62.94 bbl

This is more than the kick size so:

Influx Height (ft) = 50 ÷ 0.2098 = 238 ft

---

4) Volume (bbl) = 0.0226 x 720 = 16.27 bbl

This is less than the kick size by:

20 - 16.27 = 3.73 bbls

which sits in the DP-OH Annulus with a height of:

Influx Height (ft) = 3.73 ÷ 0.0505 = 74 ft

giving a total height of influx of:

720 + 74 = 794 ft

INFLUX GRADIENT

SICP is usually greater than SIDPP because the influx is in the annulus. This means the hydrostatic pressure in the annulus will be less than the hydrostatic pressure in the drill string.

For the well you have been looking at SIDPP = 500 psi and SICP = 630 psi. The current mud weight is 10 ppg.

The hydrostatic pressure in the annulus is less because the influx is in the annulus. You can work out the height of the influx by dividing its volume in bbl by the annular capacity in bbl/ft where the kick is sitting. Influx height worked out at 333 ft.

With this information, you can now calculate the gradient of the kick using the formula:

$$\text{Influx Gradient (psi/ft)} = (\text{Mud Weight (ppg)} \times 0.052) - \frac{\text{SICP (psi)} - \text{SIDPP (psi)}}{\text{Influx Height (ft)}}$$

Now while this looks complicated at first glance, the formula gives you all the mathematical instructions you need. There are two calculations. You have to subtract the answer to the second calculation from the answer to the first.

$$\text{Influx Gradient (psi/ft)} = (10 \times 0.052) - \frac{630 - 500}{333}$$

$$= 0.52 - 0.39039039$$

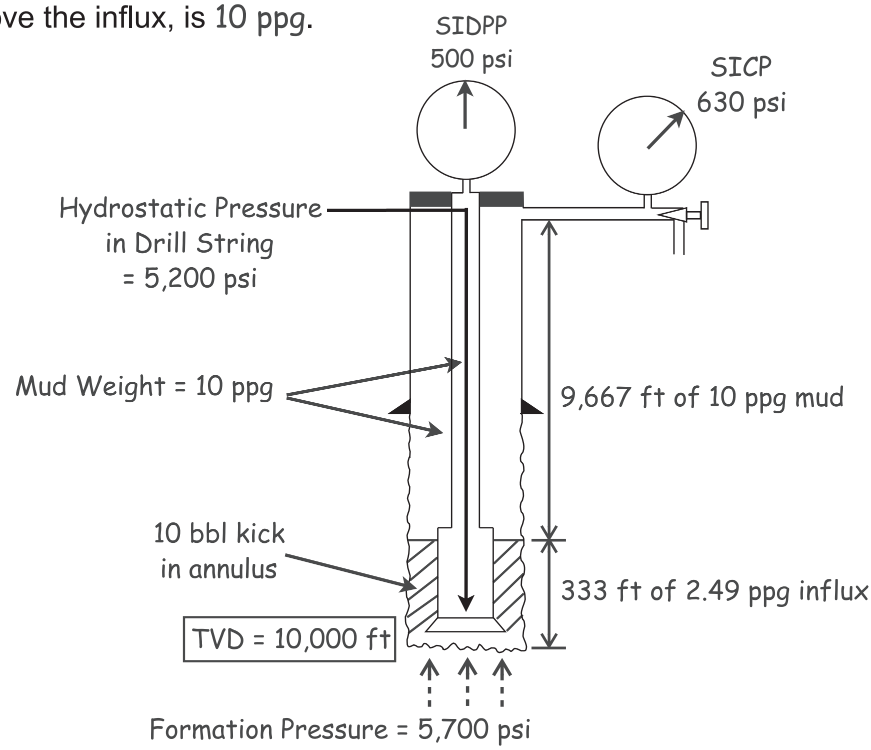
$$= \underline{0.1296 \text{ psi/ft}}$$

If you convert this to a ppg mud weight you get:

$$\text{Mud Weight (ppg)} = 0.1296 \div 0.052 = \underline{2.49 \text{ ppg}}$$

A lot lighter than the 10 ppg mud in the drill string!

So what do you know about the annulus? You know that there are 333 ft of influx down the bottom, weighing 2.49 ppg. You also know that the mud weight, above the influx, is 10 ppg.



You can now work out the combined hydrostatic pressure in the annulus.

Mud Hydrostatic Pressure (psi) = 10 x 0.052 x 9,667 = <u>5,027 psi</u>

Influx Hydrostatic Pressure (psi) = 2.49 x 0.052 x 333 = <u>43 psi</u>

Hydrostatic Pressure in Annulus (psi) = 5,027 + 43 = <u>5,070 psi</u>

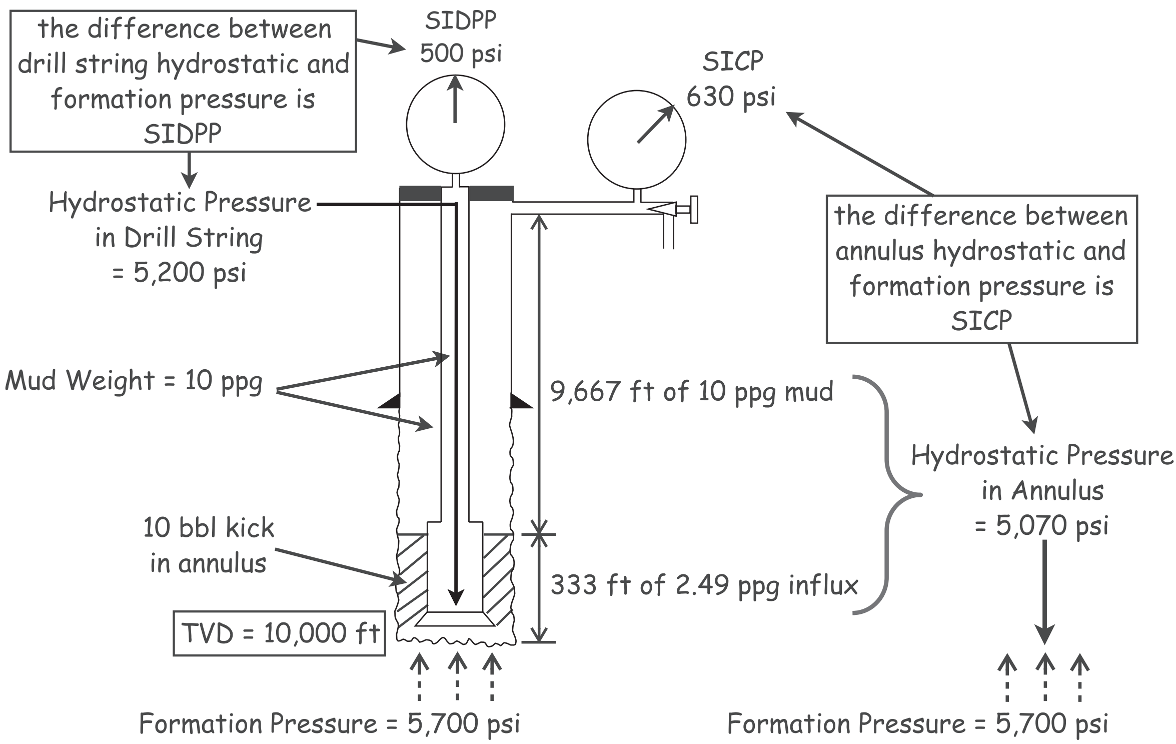
In the annulus you have 5,070 psi of hydrostatic pressure pushing down against 5,700 psi of formation pressure pushing up.

The difference, 630 psi, is SICP.

SIDPP is the difference between formation pressure pushing up and the hydrostatic pressure in the drill string pushing down.

SICP is the difference between formation pressure pushing up and the hydrostatic pressure in the annulus pushing down.

The well picture is getting busy now. Take some time to understand what is happening and why.



The well is shut in on a kick and the pressures have stabilised.

SIDPP shows how much under balance you are. If you know TVD and current mud weight you can use SIDPP to work out formation pressure.

SICP is greater than SIDPP. This is due to the light influx sitting in the annulus. SICP tells you how much you are under balance in the annulus

If you know the height of the influx you can work out its gradient using SIDPP, SICP and the current mud weight.

The formula for influx gradient is:

$$\text{Influx Gradient (psi/ft)} = (\text{Mud Weight (ppg)} \times 0.052) - \frac{\text{SICP (psi)} - \text{SIDPP (psi)}}{\text{Influx Height (ft)}}$$

The influx will take up space in the DC-OH annulus but, depending on its volume, may have extended up into the DP-OH annulus.

You can work out the height of the influx using the formula:

$$\text{Influx Height (ft)} = \text{Kick Size (bbl)} \div \text{Annular Capacity (bbl/ft)}$$

You will have to figure out where the influx is sitting in order to be able to work out its height.

Using well data one for questions 1 & 2, and well data two for questions 3 & 4, calculate the influx gradients to 4 decimal places:

Well Data One:	DC-OH Cap. = 0.0292 bbl/ft; DP-OH Cap. = 0.0459 bbl/ft;	Mud Weight = 10.6 ppg
Well Data Two:	DC-OH Cap. = 0.0226 bbl/ft; DP-OH Cap. = 0.0505 bbl/ft;	Mud Weight = 11.8 ppg

1) SIDPP = 525 psi; SICP = 700 psi; Kick Size = 18 bbl; DC Length = 675 ft

2) SIDPP = 700 psi; SICP = 960 psi; Kick Size = 24 bbl; DC Length = 710 ft

3) SIDPP = 420 psi; SICP = 610 psi; DC Length = 840 ft; Kick Size = 12 bbl

4) SIDPP = 660 psi; SICP = 1040 psi; DC Length = 765 ft; Kick Size = 27 bbl

ANSWERS

$$\text{Influx Gradient (psi/ft)} = (\text{Mud Weight (ppg)} \times 0.052) - \frac{\text{SICP (psi)} - \text{SIDPP (psi)}}{\text{Influx Height (ft)}}$$

$$\text{Influx Height (ft)} = \text{Kick Size (bbl)} \div \text{Annular Capacity (bbl/ft)}$$

$$\text{Volume (bbls)} = \text{Capacity (bbl/ft)} \times \text{Length (ft)}$$

---

1) Volume (bbl) = 0.0292 x 675 = <u>19.71 bbls</u> more than kick size

Influx Height (ft) = 18 ÷ 0.0292 = <u>616 ft</u>

$$\text{Influx Gradient (psi/ft)} = (10.6 \times 0.052) - \frac{700 - 525}{616}$$

= 0.5512 - 0.284090909 = <u>0.2671 psi/ft</u>

---

2) Volume (bbl) = 0.0292 x 710 = <u>20.73 bbl</u> less than kick size by

24 - 20.73 = <u>3.27 bbls</u>

DP-OH Influx Height (ft) = 3.27 ÷ 0.0459 = <u>71 ft</u>

giving a total height of influx of:

710 - 71 = <u>781 ft</u>

$$\text{Influx Gradient (psi/ft)} = (10.6 \times 0.052) - \frac{960 - 700}{781}$$

= 0.5512 - 0.33290653 = <u>0.2183 psi/ft</u>

3) Volume (bbl)= $0.0226 \times 840 =$ 18.98 bbl more than kick size

Influx Height (ft)= $12 \div 0.0226 =$ 531 ft

$$\text{Influx Gradient (psi/ft)} = (11.8 \times 0.052) - \frac{610 - 420}{531}$$

$$= 0.6136 - 0.357815442 \quad = \underline{0.2558 \text{ psi/ft}}$$

---

4) Volume (bbl) = $0.0226 \times 765 =$ 17.29 bbl less than kick size by

$27 - 17.29 =$ 9.71 bbl

DP-OH Influx Height (ft) = $9.71 \div 0.0505 =$ 192 ft

giving a total height of influx of:

$765 + 192 =$ 957 ft

$$\text{Influx Gradient (psi/ft)} = (11.8 \times 0.052) - \frac{1040 - 660}{957}$$

$$= 0.6136 - 0.3970741$$

$$= \underline{0.2165 \text{ psi/ft}}$$

KILL SHEET - PRESSURE CALCULATIONS

You may be asked to complete a kill sheet in a well control situation on the rig. You **will** have to complete one when you attend well control school. In chapter two you looked at the volume calculations on a kill sheet. In this chapter you will cover the pressure calculations.

Kill sheets vary from company to company and well control school to well control school. There are different layouts and sometimes different formulas. There are some calculations, however, that will be on all kill sheets. They may be in different places but they will be there somewhere.

The pressure calculations you will always find on a kill sheet are kill mud weight, ICP, FCP and MAASP. There will also be some kind of pressure reduction calculation. There may be other calculations. The kill sheet will also have space for recording data. Well TVD, Shoe TVD, Mud Weight, Maximum Mud Weight, SIDPP, SICP, Pit Gain and your Pump SCR details are all usually recorded somewhere.

Most kill sheets are generally two or more pages in length. The pre-recorded data is usually worked out on one page and the actual kill information on another. The pre-recorded information will generally include the volume calculations, your Pump SCR data and MAASP calculations.

As volume calculations were covered in section two, the kill sheet you are going to use in this section has all the pressure related calculations and data on one page. Remember that this may not be the case at the rig or on well control school.

Also remember that the layout does not matter - once you know the calculations you have to complete it will simply be a case of finding out where they are on any different kill sheet you may be asked to complete.

Have a look at the blank kill sheet opposite and find where things are. See what you already know and what has still to be covered.

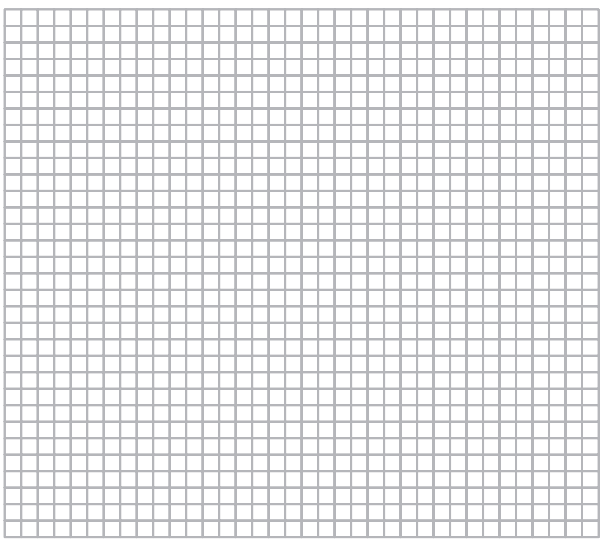
Well TVD(ft)	Shoe TVD(ft)	Current Mud Wt.(ppg)	Test Mud Wt.(ppg)	LOT Pressure(psi)
SIDPP(psi)	SICP(psi)	Pump SCR@Kill Rate(psi)	Pit Gain(bbl)	Surface to Bit Strokes

Max Mud Wt.(ppg) = (LOT Pressure(psi) ÷ Shoe TVD(ft) ÷ 0.052) + Test Mud Wt.(ppg)	
= (_______________ ÷ _______________÷ 0.052) +_______________ =	ppg
MAASP(psi) = (Max Mud Wt.(ppg) – Current Mud Wt.(ppg)) x 0.052 x Shoe TVD(ft)	
= (_______________ - _______________) x 0.052 x _______________ =	psi
Kill Mud Wt.(ppg) = (SIDPP(psi) ÷ Well TVD(ft) ÷ 0.052) + Current Mud Wt.(ppg)	
= (_______________ ÷ _______________÷ 0.052) +_______________ =	ppg
ICP(psi) = SCR Pressure(psi) + SIDPP(psi) = __________ + __________ =	psi
FCP(psi) = (Kill Mud Wt.(ppg) ÷ Current Mud Wt.ppg) x SCR Pressure(psi)	
= (_______________ ÷ _______________) x _______________ =	psi
Pressure Reduction(psi/100 stks) = (ICP(psi) - FCP(psi)) ÷ Surface to Bit Strokes(stks) x 100	
= (__________ - __________) ÷ _______________ x 100 =	psi/100 stks

Pressure Reduction Schedule	
Strokes (Surf to Bit)	Pressure (ICP to FCP)

Dynamic & Static Step Down Graphs

Pressure



Strokes

Plenty of stuff there you recognise for sure. But what's that pressure reduction schedule all about? And who stuck a graph in there?

The top half of this kill sheet is revision. There are a couple of rows for data input followed by five calculations you already know how to do.

Enter relevant data in boxes.
Work from the kill sheet rather than the question where possible.

Well TVD(ft)	Shoe TVD(ft)	Current Mud Wt.(ppg)	Test Mud Wt.(ppg)	LOT Pressure(psi)
SIDPP(psi)	SICP(psi)	Pump SCR@Kill Rate(psi)	Pit Gain(bbl)	Surface to Bit Strokes

Max Mud Wt.(ppg) = (LOT Pressure(psi) ÷ Shoe TVD(ft) ÷ 0.052) + Test Mud Wt.(ppg)	
= (________ ÷ ________ ÷ 0.052) + ________ =	ppg
MAASP(psi) = (Max Mud Wt.(ppg) – Current Mud Wt.(ppg)) x 0.052 x Shoe TVD(ft)	
= (________ - ________) x 0.052 x ________ =	psi
Kill Mud Wt.(ppg) = (SIDPP(psi) ÷ Well TVD(ft) ÷ 0.052) + Current Mud Wt.(ppg)	
= (________ ÷ ________ ÷ 0.052) + ________ =	ppg
ICP(psi) = SCR Pressure(psi) + SIDPP(psi) = ______ + ______ =	psi
FCP(psi) = (Kill Mud Wt.(ppg) ÷ Current Mud Wt.ppg) x SCR Pressure(psi)	
= (________ ÷ ________) x ________ =	psi

Complete the calculations.
No need to find formulas - just enter the correct data and away you go!

The bottom half of the page is new. You have already seen that drill pipe pressure reduces from ICP to FCP as kill mud is pumped down the drill string from surface to bit. During a well kill operation you need to know what the pressure should be at any time as kill mud is being pumped down the drill string.

On this kill sheet, you have been asked to calculate how much the pressure should reduce by for every 100 strokes of kill mud pumped. Input the data and the calculation is straightforward. This value is then used in the pressure reduction schedule, to track the drop in pressure, versus the strokes pumped.

On the pressure reduction schedule you record strokes every 100, from zero to your surface to bit total. With zero strokes pumped the pressure will be ICP. It will drop by your calculated psi/100 strokes value for every 100 strokes pumped until kill mud reaches the bit when the pressure will be FCP.

The graph is used to plot the drop in pressure versus the strokes pumped, both dynamically (while pumping) and statically (shut in).

The dynamic line falls from ICP to FCP - it tracks your expected pump pressure.

The static line falls from SIDPP to zero. Before you start pumping kill mud your drill pipe gauge reads SIDPP. If you were to shut down with kill mud at the bit, then you will have killed the drill string and SIDPP will read zero.

If you had to shut down the kill operation, with kill mud part-way to the bit, the static line shows you what the shut in pressure should read.

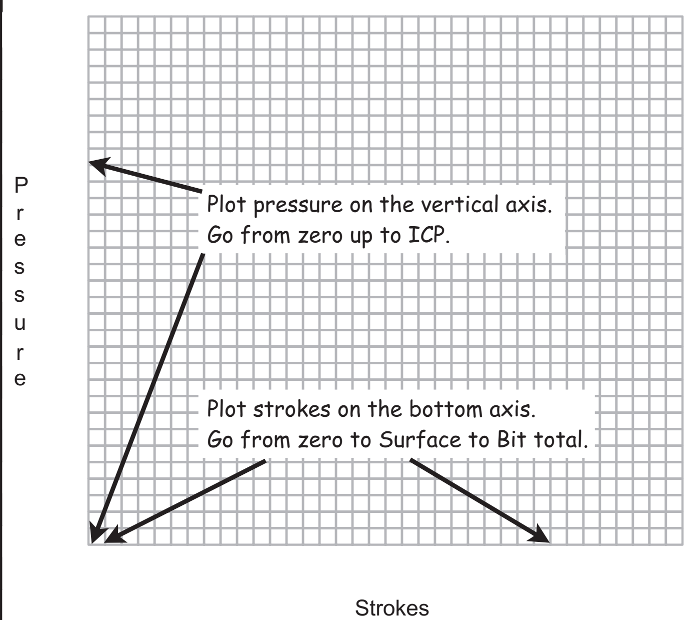
Pressure Reduction(psi/100 stks) = (ICP(psi) - FCP(psi)) ÷ Surface to Bit Strokes(stks) x 100

= (__________ - ___________) ÷ _______________ x 100 = | psi/100 stks

Pressure Reduction Schedule

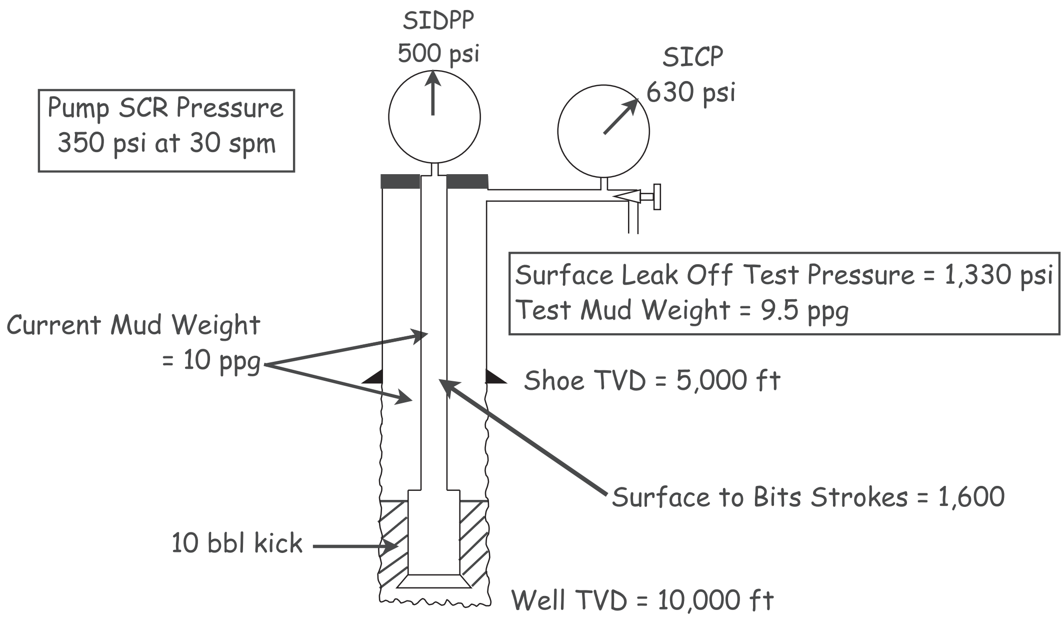
Strokes (Surf to Bit)	Pressure (ICP to FCP)

Dynamic & Static Step Down Graphs



OK, time to see the kill sheet in action.

Here are the shut in conditions for the well you have been looking at throughout this section.



Leak off test data has also been given along with the shoe TVD.

Complete the kill sheet opposite for this well. Ensure you complete the pressure reduction schedule and draw the two graphs.

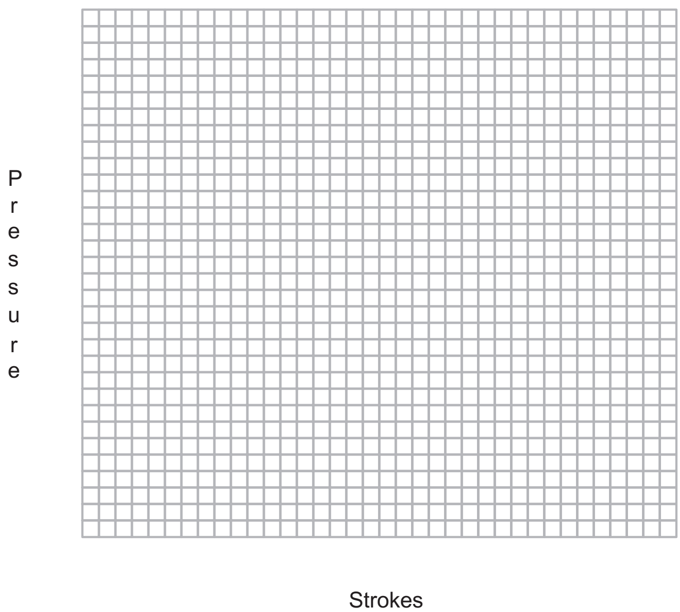
If you do not want to write in this book then you will need to take a copy of the kill sheet. Make a few while you are at it as you will need to complete more later.

Well TVD(ft)	Shoe TVD(ft)	Current Mud Wt.(ppg)	Test Mud Wt.(ppg)	LOT Pressure(psi)
SIDPP(psi)	**SICP(psi)**	**Pump SCR@Kill Rate(psi)**	**Pit Gain(bbl)**	**Surface to Bit Strokes**

Max Mud Wt.(ppg) = (LOT Pressure(psi) ÷ Shoe TVD(ft) ÷ 0.052) + Test Mud Wt.(ppg)	
= (______________ ÷ ______________÷ 0.052) +_____________ =	ppg
MAASP(psi) = (Max Mud Wt.(ppg) – Current Mud Wt.(ppg)) x 0.052 x Shoe TVD(ft)	
= (______________ - ______________) x 0.052 x _____________ =	psi
Kill Mud Wt.(ppg) = (SIDPP(psi) ÷ Well TVD(ft) ÷ 0.052) + Current Mud Wt.(ppg)	
= (______________ ÷ ______________÷ 0.052) +_____________ =	ppg
ICP(psi) = SCR Pressure(psi) + SIDPP(psi) = __________ + __________ =	psi
FCP(psi) = (Kill Mud Wt.(ppg) ÷ Current Mud Wt.ppg) x SCR Pressure(psi)	
= (______________ ÷ ______________) x ______________ =	psi
Pressure Reduction(psi/100 stks) = (ICP(psi) - FCP(psi)) ÷ Surface to Bit Strokes(stks) x 100	
= (_________ - __________) ÷ ______________ x 100 =	psi/100 stks

Pressure Reduction Schedule	
Strokes (Surf to Bit)	**Pressure (ICP to FCP)**

Dynamic & Static Step Down Graphs



Well TVD(ft)	Shoe TVD(ft)	Current Mud Wt.(ppg)	Test Mud Wt.(ppg)	LOT Pressure(psi)
10,000	5,000	10	9.5	1,330
SIDPP(psi)	**SICP(psi)**	**Pump SCR@Kill Rate(psi)**	**Pit Gain(bbl)**	**Surface to Bit Strokes**
500	630	350	10	1,600

Max Mud Wt.(ppg) = (LOT Pressure(psi) ÷ Shoe TVD(ft) ÷ 0.052) + Test Mud Wt.(ppg)

= (1,330 ÷ 5,000 ÷ 0.052) + 9.5 = **14.6** ppg

MAASP(psi) = (Max Mud Wt.(ppg) – Current Mud Wt.(ppg)) x 0.052 x Shoe TVD(ft)

= (14.6 - 10) x 0.052 x 5,000 = **1,196** psi

Kill Mud Wt.(ppg) = (SIDPP(psi) ÷ Well TVD(ft) ÷ 0.052) + Current Mud Wt.(ppg)

= (500 ÷ 10,000 ÷ 0.052) + 10 = **11** ppg

ICP(psi) = SCR Pressure(psi) + SIDPP(psi) = 350 + 500 = **850** psi

FCP(psi) = (Kill Mud Wt.(ppg) ÷ Current Mud Wt.ppg) x SCR Pressure(psi)

= (11 ÷ 10) x 350 = **385** psi

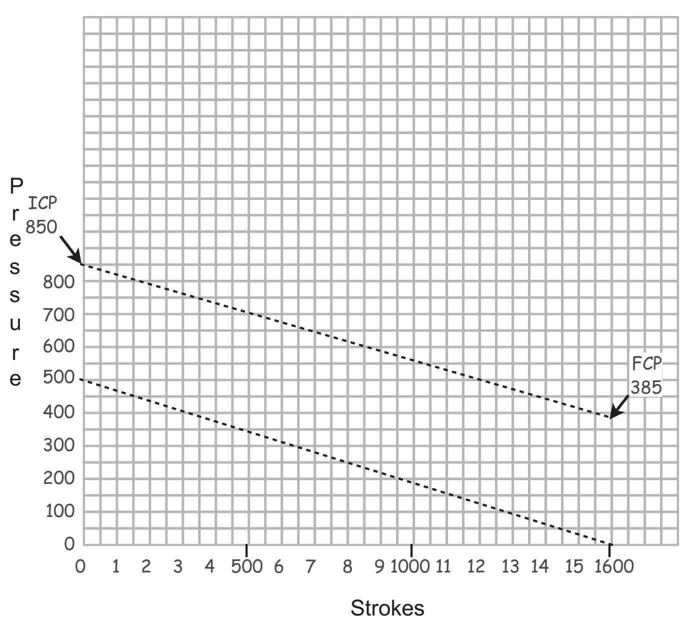
Pressure Reduction(psi/100 stks) = (ICP(psi) - FCP(psi)) ÷ Surface to Bit Strokes(stks) x 100

= (850 - 385) ÷ 1,600 x 100 = **29** psi/100 stks

Pressure Reduction Schedule

Strokes (Surf to Bit)	Pressure (ICP to FCP)
0	850
100	821
200	792
300	763
400	734
500	705
600	676
700	647
800	618
900	589
1,000	560
1,100	531
1,200	502
1,300	473
1,400	444
1,500	415
1,600	385

Dynamic & Static Step Down Graphs



What have you discovered?

Hopefully you have discovered that the kill sheet is nothing to be scared about. The pressure calculations on the kill sheet, as with the volume calculations, are reasonably straightforward.

There will be space on the kill sheet for you to record data. It may not all be on one page as with this one. Usually depths will be recorded on the same page as the volume calculations.

Formation strength data and calculations (max mud weight and MAASP) may also be on a separate page. You may also be asked to work out MAASP after the kill. Just substitute kill mud weight for current mud weight in the formula and away you go.

Note how the pressure reduction schedule starts at zero strokes pumped and goes up in hundreds to the surface to bit total. Note how at zero strokes pumped the pressure is ICP and that it reduces by the psi/100 stks value (in this case 29 psi/100 stks) for every hundred strokes pumped. Once you have pumped surface to bit strokes note that the pressure is FCP. Due to rounding the final step can sometimes be bigger or smaller than the rest.

Have a look at the two graphs. The top line is the dynamic (or pumping pressure) graph. It ties in with the pressure reduction schedule you calculated. and falls from ICP to FCP. If you have drawn an accurate graph, then you should be able to cross-reference the pump strokes against the pressure against the schedule.

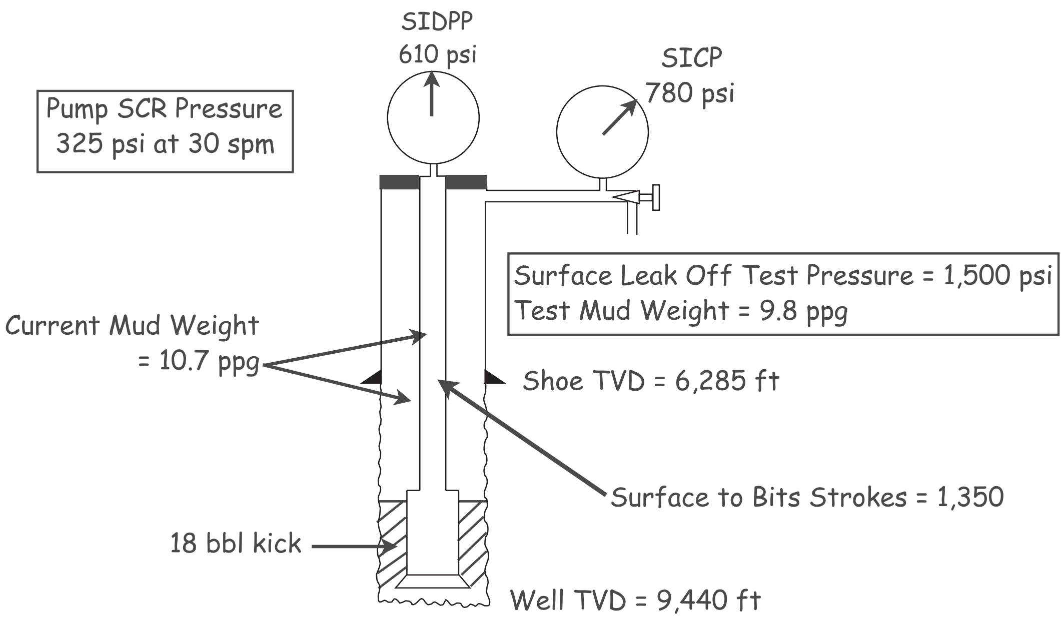
Find 1,200 strokes along the bottom axis. Follow this line up to where it crosses the dynamic pressure graph. What pressure does it read? How does this tie in with the value for 1,200 strokes on the pressure reduction schedule?

The lower line is the static line. This shows what the pressure should read when you are not pumping and the well is shut in. It starts at original SIDPP (you have not yet pumped any kill mud) and falls to zero by the time you have pumped surface to bit strokes. Remember, you will have filled the drill string with kill mud which means you will have killed the string. This line would be used to check the pressure if you had to shut down with kill mud part-way to the bit.

OK, try another one.

Complete the kill sheet opposite (or a copy) for the well below. Include the pressure reduction schedule and both graphs.

If you want to use your own company kill sheet then please feel free to do so. Just remember that it will be laid out differently and that things will be in different places.



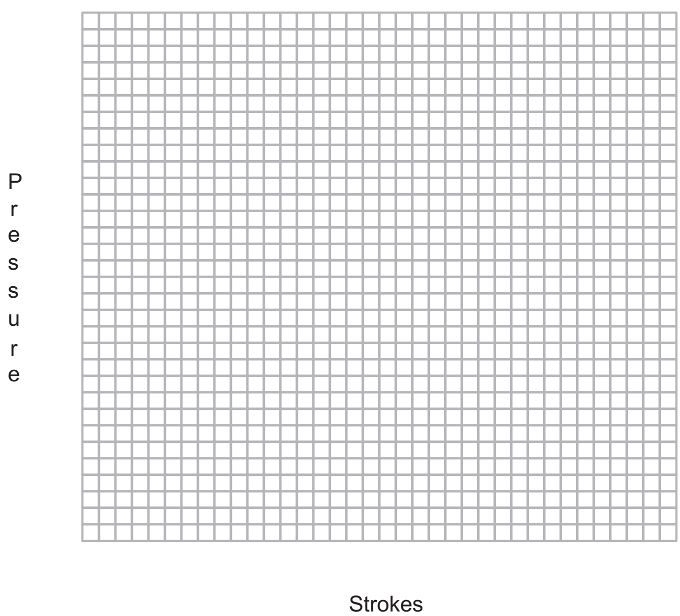
Well TVD(ft)	Shoe TVD(ft)	Current Mud Wt.(ppg)	Test Mud Wt.(ppg)	LOT Pressure(psi)
SIDPP(psi)	SICP(psi)	Pump SCR@Kill Rate(psi)	Pit Gain(bbl)	Surface to Bit Strokes

Max Mud Wt.(ppg) = (LOT Pressure(psi) ÷ Shoe TVD(ft) ÷ 0.052) + Test Mud Wt.(ppg)	
= (_______________ ÷ _______________÷ 0.052) +_______________ =	ppg
MAASP(psi) = (Max Mud Wt.(ppg) – Current Mud Wt.(ppg)) x 0.052 x Shoe TVD(ft)	
= (_______________ - _______________) x 0.052 x _______________ =	psi
Kill Mud Wt.(ppg) = (SIDPP(psi) ÷ Well TVD(ft) ÷ 0.052) + Current Mud Wt.(ppg)	
= (_______________ ÷ _______________÷ 0.052) +_______________ =	ppg
ICP(psi) = SCR Pressure(psi) + SIDPP(psi) = __________ + __________ =	psi
FCP(psi) = (Kill Mud Wt.(ppg) ÷ Current Mud Wt.ppg) x SCR Pressure(psi)	
= (_______________ ÷ _______________) x _______________ =	psi
Pressure Reduction(psi/100 stks) = (ICP(psi) - FCP(psi)) ÷ Surface to Bit Strokes(stks) x 100	
= (__________ - __________) ÷ _______________ x 100 =	psi/100 stks

Pressure Reduction Schedule

Strokes (Surf to Bit)	Pressure (ICP to FCP)

Dynamic & Static Step Down Graphs



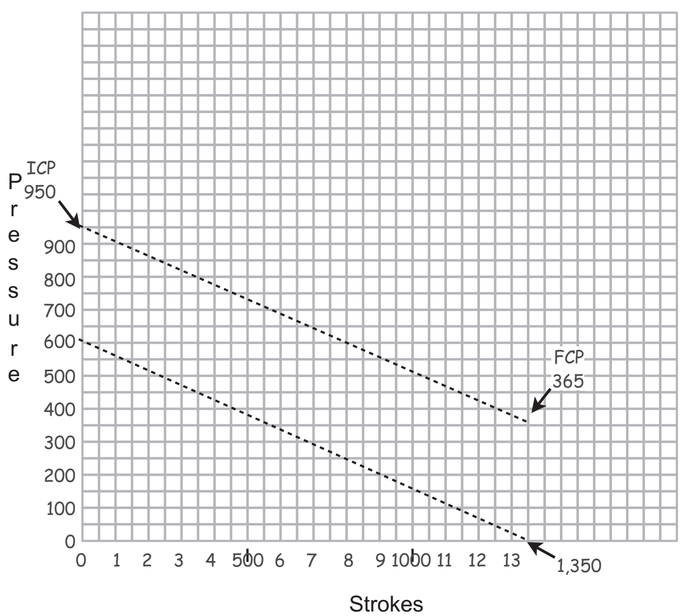
Well TVD(ft)	Shoe TVD(ft)	Current Mud Wt.(ppg)	Test Mud Wt.(ppg)	LOT Pressure(psi)
9,440	6,285	10.7	9.8	1,500
SIDPP(psi)	SICP(psi)	Pump SCR@Kill Rate(psi)	Pit Gain(bbl)	Surface to Bit Strokes
610	780	325	18	1,350

Max Mud Wt.(ppg) = (LOT Pressure(psi) ÷ Shoe TVD(ft) ÷ 0.052) + Test Mud Wt.(ppg)	
= (1,500 ÷ 6,285 ÷ 0.052) + 9.8 =	**14.3** ppg
MAASP(psi) = (Max Mud Wt.(ppg) – Current Mud Wt.(ppg)) x 0.052 x Shoe TVD(ft)	
= (14.3 - 10.7) x 0.052 x 6,285 =	**1,176** psi
Kill Mud Wt.(ppg) = (SIDPP(psi) ÷ Well TVD(ft) ÷ 0.052) + Current Mud Wt.(ppg)	
= (610 ÷ 9,440 ÷ 0.052) + 10.7 =	**12** ppg
ICP(psi) = SCR Pressure(psi) + SIDPP(psi) = 325 + 610 =	**935** psi
FCP(psi) = (Kill Mud Wt.(ppg) ÷ Current Mud Wt.ppg) x SCR Pressure(psi)	
= (12 ÷ 10.7) x 325 =	**365** psi
Pressure Reduction(psi/100 stks) = (ICP(psi) - FCP(psi)) ÷ Surface to Bit Strokes(stks) x 100	
= (935 - 365) ÷ 1,350 x 100 =	**42** psi/100 stks

Pressure Reduction Schedule

Strokes (Surf to Bit)	Pressure (ICP to FCP)
0	935
100	893
200	851
300	809
400	767
500	725
600	683
700	641
800	599
900	557
1,000	515
1,100	473
1,200	431
1,300	389
1,350	365

Dynamic & Static Step Down Graphs



The kill sheet, regardless of which one you use, should not pose any problems for you now. All kill sheets contain some volume calculations and some pressure calculations. These will be pretty much the same regardless of what kill sheet you are using.

When you get the chance you should get a hold of your company kill sheet and complete it for the two wells detailed in this section. Note anything that is different but also note where things are the same. It will also be worthwhile doing this for the volume calculations and wells detailed in section two if you have not already done so.

Well, that's it for this chapter. There are more well control calculations than those you have covered here but many of them require some explanation and more understanding of well control before they become relevant. You will be introduced to them when you attend well control school.

In this chapter you have been introduced to some well control concepts and now have a basic understanding of some of the underlying principles. You will also be comfortable with the main well control calculations.

Topics covered in this section include:

Formation pressure
Balance, overbalance & underbalance
Kill mud weight
ICP
FCP
Influx height
Influx gradient
Kill sheet pressure calculations

Take some time to have a look through the chapter again. Revise anything you are unsure of before turning the page as the chapter test is coming up.

All the formulas you need are given.

No need for good luck this time is there?

FORMULAS

$$\text{Influx Gradient (psi/ft)} = (\text{Mud Weight (ppg)} \times 0.052) - \frac{\text{SICP (psi)} - \text{SIDPP (psi)}}{\text{Influx Height (ft)}}$$

$$\text{Influx Height (ft)} = \text{Kick Size (bbl)} \div \text{Annular Capacity (bbl/ft)}$$

$$\text{Volume (bbl)} = \text{Capacity (bbl/ft)} \times \text{Length (ft)}$$

$$\text{Formation Pressure (psi)} = \text{Hydrostatic Pressure in Drill String (psi)} + \text{SIDPP (psi)}$$

$$\text{Formation Pressure (psi)} = \text{Formation Pressure Gradient (psi/ft)} \times \text{TVD (ft)}$$

$$\text{Hydrostatic Pressure (psi)} = \text{Mud Weight (ppg)} \times 0.052 \times \text{TVD (ft)}$$

$$\text{Hydrostatic Pressure (psi)} = \text{Formation Pressure (psi)} + \text{Overbalance (psi)}$$

$$\text{Kill Mud Weight (ppg)} = \frac{\text{SIDPP (psi)}}{\text{Well TVD (ft)} \times 0.052} + \text{Current Mud Weight (ppg)}$$

WELL DATA ONE

Well TVD = 15,770 ft; Current Mud Weight = 13.4 ppg; SICP = 650 psi;
DC-OH Cap = 0.03 bbl/ft; Formation Pressure Gradient = 0.72 psi/ft;
Pit Gain = 17 bbl; DC Length = 680 ft

WELL DATA TWO

Well TVD = 9,286 ft; Current Mud Weight = 9.9 ppg; SICP = 770 psi;
Pit Gain = 26 bbl; SIDPP = 550 psi; DC Length = 680 ft;
DC-OH Cap = 0.03 bbl/ft; DP-OH Cap = 0.0459 bbl/ft

CHAPTER TEST

Use well data one to answer questions 1 - 4 below.

1) What is formation pressure?

2) What is SIDPP?

3) What is the influx gradient?

4) The mud weight in use assumed there was an overbalance of 250 psi. What did they think formation pressure was before the kick?

Use well data two to answer questions 5 - 8 below.

5) What kill mud weight is needed?

6) What is formation pressure?

7) What is the gradient of the influx?

8) What mud weight will be needed after the kill if it is to include a 200 psi overbalance?

CHAPTER TEST CONTINUED ON NEXT PAGE

CHAPTER TEST CONTINUED FROM PREVIOUS PAGE

9) Complete the kill sheet opposite (or a copy) using the well data below.

Well TVD = 10,450 ft

Shoe TVD = 8,876 ft

Surface to Bit Strokes = 1,650 stk

LOT Pressure = 1,950 psi

Test Mud Weight = 10.7 ppg

Current Mud Weight = 11.6 ppg

SCR Pressure @ Kill Rate = 425 psi

SIDPP = 675 psi

SICP = 800 psi

Pit Gain = 24 bbl

Well TVD(ft)	Shoe TVD(ft)	Current Mud Wt.(ppg)	Test Mud Wt.(ppg)	LOT Pressure(psi)
SIDPP(psi)	SICP(psi)	Pump SCR@Kill Rate(psi)	Pit Gain(bbl)	Surface to Bit Strokes

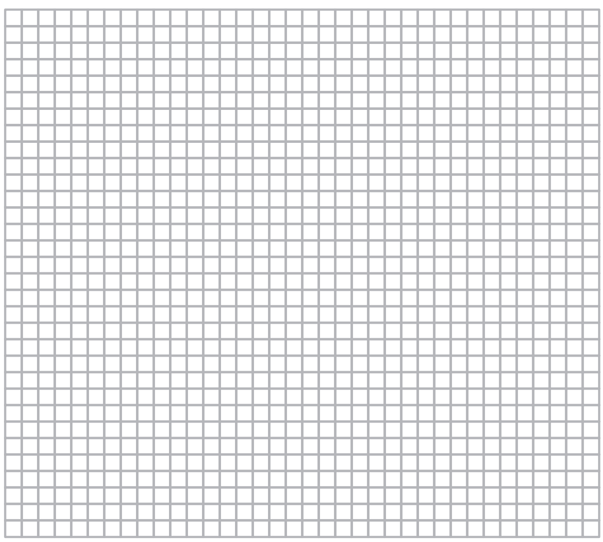
Formula	Result
Max Mud Wt.(ppg) = (LOT Pressure(psi) ÷ Shoe TVD(ft) ÷ 0.052) + Test Mud Wt.(ppg)	
= (______________ ÷ ______________÷ 0.052) +______________ =	ppg
MAASP(psi) = (Max Mud Wt.(ppg) – Current Mud Wt.(ppg)) x 0.052 x Shoe TVD(ft)	
= (______________ - ______________) x 0.052 x ______________ =	psi
Kill Mud Wt.(ppg) = (SIDPP(psi) ÷ Well TVD(ft) ÷ 0.052) + Current Mud Wt.(ppg)	
= (______________ ÷ ______________÷ 0.052) +______________ =	ppg
ICP(psi) = SCR Pressure(psi) + SIDPP(psi) = __________ + __________ =	psi
FCP(psi) = (Kill Mud Wt.(ppg) ÷ Current Mud Wt.ppg) x SCR Pressure(psi)	
= (______________ ÷ ______________) x ______________ =	psi
Pressure Reduction(psi/100 stks) = (ICP(psi) - FCP(psi)) ÷ Surface to Bit Strokes(stks) x 100	
= (__________ - __________) ÷ ______________ x 100 =	psi/100 stks

Pressure Reduction Schedule

Strokes (Surf to Bit)	Pressure (ICP to FCP)

Dynamic & Static Step Down Graphs

Pressure



Strokes

ANSWERS

1) Formation Pressure (psi) = Formation Pressure Gradient (psi/ft) x TVD (ft)

= 0.72 x 15,770 = <u>11,354 psi</u>

---

2) Formation Pressure (psi) = Hydrostatic Pressure in Drill String (psi) + SIDPP(psi)

therefore:

SIDPP (psi) = Formation Pressure (psi) - Hydrostatic Pressure in Drill String (psi)

Hydrostatic Pressure in Drill String (psi)= 13.4 x 0.052 x 15,770

= <u>10,989 psi</u>

SIDPP(psi) = 11,354 - 10,989 = <u>365 (psi)</u>

---

3) $$\text{Influx Gradient (psi/ft)} = (\text{Mud Weight (ppg)} \times 0.052) - \frac{\text{SICP (psi)} - \text{SIDPP (psi)}}{\text{Influx Height (ft)}}$$

DC-OH Annular Volume (bbls)= Capacity (bbl/ft) x Length (ft)

= 0.03 x 680 = <u>20.4 bbls</u>

This is more than kick volume therefore:

Influx Height (ft)= Kick Size (bbl) ÷ Annular Capacity (bbl/ft)

= 17 ÷ 0.03 = <u>567 ft</u>

Q3 continued ...

$$\text{Influx Gradient (psi/ft)} = (\text{Mud Weight (ppg)} \times 0.052) - \frac{\text{SICP (psi)} - \text{SIDPP (psi)}}{\text{Influx Height (ft)}}$$

$$\text{Influx Gradient (psi/ft)} = (13.4 \times 0.052) - \frac{650 - 365}{567}$$

$$= 0.6968 - 0.502645502$$

$$= \underline{0.1942 \text{ psi/ft}}$$

---

4) $\text{Hydrostatic Pressure (psi)} = \text{Formation Pressure (psi)} + \text{Overbalance (psi)}$

therefore assumed:

$$\text{Formation Pressure (psi)} = \text{Hydrostatic Pressure (psi)} - \text{Overbalance (psi)}$$

$$= 10{,}989 - 250 = \underline{10{,}739 \text{ psi}}$$

---

5) $$\text{Kill Mud Weight (ppg)} = \frac{\text{SIDPP (psi)}}{\text{Well TVD (ft)} \times 0.052} + \text{Current Mud Weight (ppg)}$$

$$= \frac{550}{9{,}286 \times 0.052} + 9.9$$

$$= \frac{550}{482.872} + 9.9$$

$$= 1.139018207 + 9.9 = 11.0390182$$

$$= \underline{11.1 \text{ ppg}}$$

6) Formation Pressure (psi) = Hydrostatic Pressure in Drill String (psi) + SIDPP(psi)

Hydrostatic Pressure in Drill String (psi) = 9.9 x 0.052 x 9,286

= 4,780 psi

Formation Pressure (psi) = 4,780 + 550 = 5,330 psi

---

7) Influx Gradient (psi/ft) = (Mud Weight (ppg) x 0.052) - $\frac{\text{SICP (psi) - SIDPP (psi)}}{\text{Influx Height (ft)}}$

DC-OH Annular Volume (bbls) = Capacity (bbl/ft) x Length (ft)

= 0.03 x 680 = 20.4 bbl

This is less than kick size by:

26 - 20.4 = 5.6 bbl

Therefore height of influx in DP-OH Annulus is:

Influx Height (ft) = Kick Size (bbl) ÷ Annular Capacity (bbl/ft)

= 5.6 ÷ 0.0459 = 122 ft

meaning total height of influx is:

680 + 122 = 802 ft

Q7 continued ...

$$\text{Influx Gradient (psi/ft)} = (\text{Mud Weight (ppg)} \times 0.052) - \frac{\text{SICP (psi)} - \text{SIDPP (psi)}}{\text{Influx Height (ft)}}$$

$$\text{Influx Gradient (psi/ft)} = (9.9 \times 0.052) - \frac{770 - 550}{802}$$

$$= 0.5148 - 0.274314214$$

$$= \underline{0.2405 \text{ psi/ft}}$$

---

8) Hydrostatic Pressure (psi) = Formation Pressure (psi) + Overbalance (psi)

$$= 5{,}330 + 200 = \underline{5{,}530 \text{ psi}}$$

Hydrostatic Pressure (psi) = Mud Weight (ppg) x 0.052 x TVD (ft)

therefore:

$$\text{Mud Weight (ppg)} = \text{Hydrostatic Pressure (psi)} \div \text{TVD (ft)} \div 0.052$$

$$= 5{,}530 \div 9{,}286 \div 0.052$$

$$= \underline{11.45 \text{ ppg}}$$

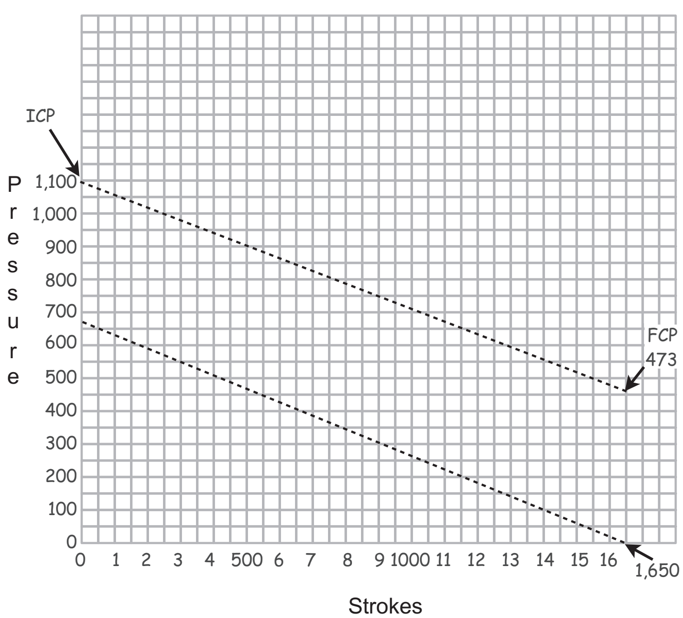
Well TVD(ft)	Shoe TVD(ft)	Current Mud Wt.(ppg)	Test Mud Wt.(ppg)	LOT Pressure(psi)
10,450	8,876	11.6	10.7	1,950
SIDPP(psi)	**SICP(psi)**	**Pump SCR@Kill Rate(psi)**	**Pit Gain(bbl)**	**Surface to Bit Strokes**
675	800	425	24	1,650

Formula / Calculation	Result
Max Mud Wt.(ppg) = (LOT Pressure(psi) ÷ Shoe TVD(ft) ÷ 0.052) + Test Mud Wt.(ppg)	
= (1,950 ÷ 8,876 ÷ 0.052) + 10.7 =	**14.9** ppg
MAASP(psi) = (Max Mud Wt.(ppg) – Current Mud Wt.(ppg)) x 0.052 x Shoe TVD(ft)	
= (14.9 - 11.6) x 0.052 x 8,876 =	**1,523** psi
Kill Mud Wt.(ppg) = (SIDPP(psi) ÷ Well TVD(ft) ÷ 0.052) + Current Mud Wt.(ppg)	
= (675 ÷ 10,450 ÷ 0.052) + 11.6 =	**12.9** ppg
ICP(psi) = SCR Pressure(psi) + SIDPP(psi) = 425 + 675 =	**1,100** psi
FCP(psi) = (Kill Mud Wt.(ppg) ÷ Current Mud Wt.ppg) x SCR Pressure(psi)	
= (12.9 ÷ 11.6) x 425 =	**473** psi
Pressure Reduction(psi/100 stks) = (ICP(psi) - FCP(psi)) ÷ Surface to Bit Strokes(stks) x 100	
= (1,100 - 473) ÷ 1,650 x 100 =	**38** psi/100 stks

Pressure Reduction Schedule

Strokes (Surf to Bit)	Pressure (ICP to FCP)
0	1,100
100	1,062
200	1,024
300	986
400	948
500	910
600	872
700	834
800	796
900	758
1,000	720
1,100	682
1,200	644
1,300	606
1,400	568
1,500	530
1,600	492
1,650	473

Dynamic & Static Step Down Graphs



FINAL SCORE

Use the marking table below to score how well you did in the chapter test.

Question	Answer	Correct or Incorrect	Value	Your Score
1	11,354 psi		3	
2	365 psi		3	
3	0.1942 psi/ft		3	
4	10,739 psi		3	
5	11.1 ppg		3	
6	5,330 psi		3	
7	0.2405 psi/ft		3	
8	11.45 ppg		3	
9 kill sheet max mud weight	14.9 ppg		3	
9 kill sheet MAASP	1,523 psi		3	
9 kill sheet kill mud weight	12.9 ppg		3	
9 kill sheet ICP	1,100 psi		3	
9 kill sheet FCP	473 psi		3	
9 kill sheet psi/100 stks	38 psi/100 stks		3	
Total Score Available = 42 Points		Your Total Score =		

Your Score = __________ ÷ 42 x 100 = [%]

Round to the nearest whole percentage. If you scored 70% or above then you passed.

LAST WORD

That's it - you have made it to the end of the book - well done.

Through the four chapters in this Introduction to Well Control Calculations for Drilling Operations you have learned:

> How to tackle calculations. This will help you with any calculations you may come across in life.
>
> How to apply your calculation skills to work out well related volumes.
>
> Some basic of well pressures and and the underpinning principles involved.
>
> Some basics of well control and the key calculations used in well control.

If you have done all this honestly then you are ready for well control school.

At well control school you will learn a few more calculations, but, if you apply the mathematical rules you have learned in this series, the new calculations will not trouble you.

This means you will be able to focus on learning well control which after all is the main reason for attending well control school!! And what's more you will be able to enjoy the experience.

NOTES