The Oil Drum
DISCUSSIONS ABOUT ENERGY AND OUR FUTURE

Permeability and Initial Oil Production

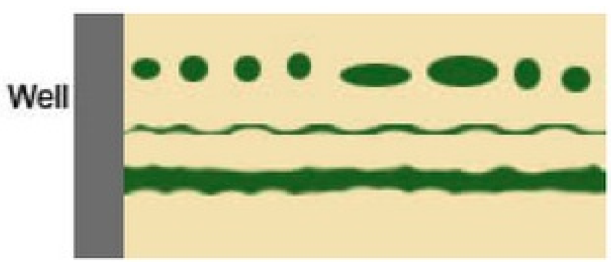
Posted by Heading Out on September 27, 2009 - 11:13am
Topic: Supply/Production
Tags: d'arcy's law, differential pressure, oil well flow, porosity, tech talk [list all tags]

This is part of Heading Out's Sunday tech talk series.

We got oil! We have put together the drill, mounted it on the derrick, circulated mud and drilled a well and used casing to line it, and a Christmas Tree to control it, and we found a layer of rock with the right porosity, and it has oil in it. Hell-lo, Beverly Hills!

Ah, but hold on a moment gentle folk, aren't we forgetting that to get the oil out of the ground, it first has to get to the well. The basics of this aren't particularly complex, but within this topic of oil well production lies a scientific reason that production goes down in an oil field as the field gets older.

I'm going to begin by making a slight correction. Last time while I talked about sandstones and carbonates, I did not explain the second group very well. And because the structure of a carbonate field is often quite different from one that occurs in sandstone, I am going to put the more generic post on production from carbonates off another week. Save only to say that the carbonates are usually limestones (including chalks) and dolomite, and that because these are very fine grained rocks, but easier to dissolve, the oil is more often found in the joints and cracks and dissolved holes in these rocks, than it is evenly spread through the rock. In contrast, with sandstone, the oil is often in the pore spaces that are spread throughout the rock, and so let's assume for now that we've got oil within a sandstone layer.



Different types of holes (porosity) in which oil green) might be found near an oil well (grey).

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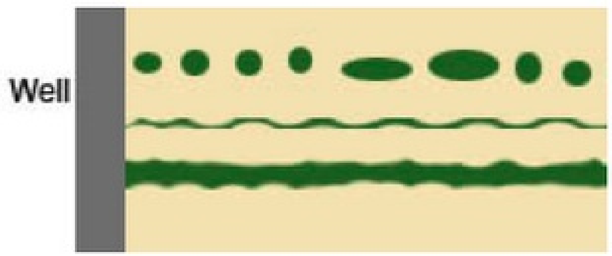


Different types of holes (porosity) in which oil (green) might be found near an oil well (grey).

The sketch shows three different layers of oil lying next to a well. In the top case none of the little pockets of oil connects to another, nor do any reach the well. (Like the holes in a swiss cheese they can be large, but are not connected one to another.) If the entire rock were like this, even though it had **porosity**, and a fair bit of oil, none of it could be extracted, since none of it could flow to the well. Now we can make a path for such oil to get to the well, but this artificial stimulation of the well (through hydrofracing and its variants) is a secondary process that we will also leave until later. What we need is a clear path that connects all the oil that sits between the grains of sand to have a path to the well, similar, perhaps, to that shown by the second layer of green (for oil) in the sketch.

The existence of flow paths in the rock is known as the **permeability** of the rock. It is a measure of how easy it is for oil to move through the passageways that it finds in the rock. These are the interconnected spaces, and the fractures and breaks that occur in the rock.

The law describing the flow of fluid through rock is known as Darcy's Law. (I'm not actually putting the equation in the post – but it can be found at the citation, together with the terms that go into it.) However, in simple terms it says that the volume of liquid flowing through a rock is going to be a function of the area of the rock through which the flow occurs, multiplied by the pressure difference between the two faces at each end of the flow path, multiplied by a constant which is related to the ease with which the oil can flow through the rock, and divided by the length of the rock path. We'll assume that the volume that the rock will flow through is a constant (it's the side of the well), so the area over which the flow will take place is also a constant.

When we had reached the rock just above the oil reservoir we had a break while we discussed the difference in pressure between the fluid in the well and the fluid in the rock. At the time we set the well pressure at 3,000 psi and the pore pressure, the pressure of the oil in the rock, at 5,000 psi. The difference in pressures, that 2,000 psi is the driving pressure that will push/pull the oil to move it to the well. This is the pressure drop that exists in the rock from the **background**

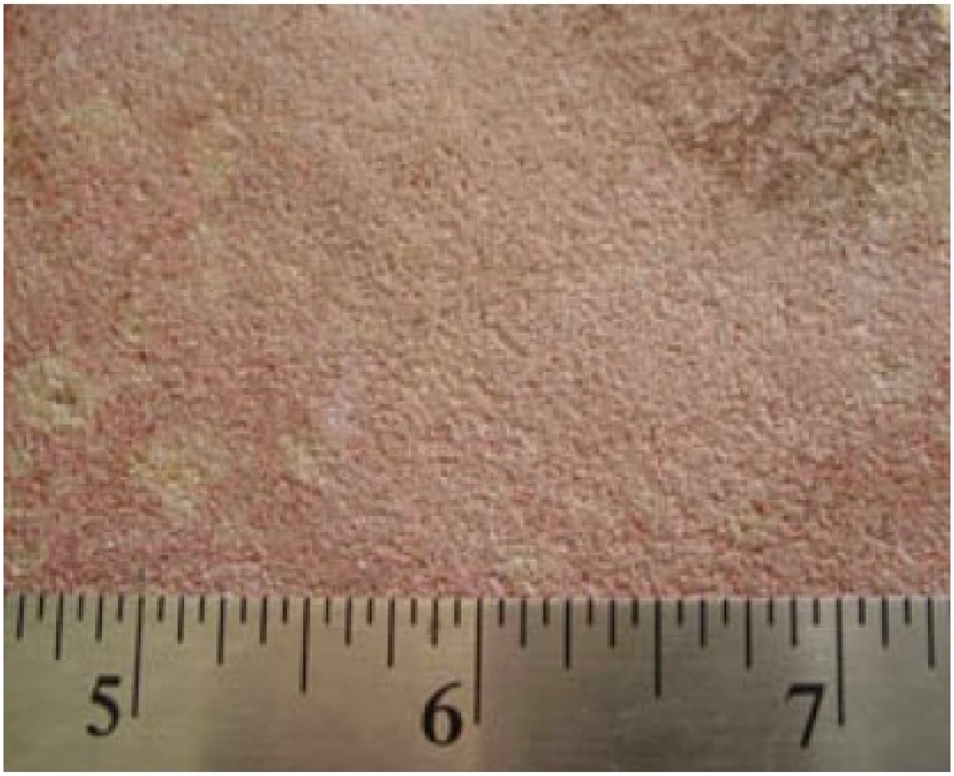
pressure to the well. (As the oil flows the pressure along the path that it flows will start to drop.) The **hydraulic conductivity** is a phrase used to describe the resistance that the rock gives to the oil moving through it. (You might think of it as a reverse friction--in other words the higher the number the less resistance there is to flow.) A wide crack in the rock, with almost smooth sides (the third row above) has a higher conductivity than the second where the gap is narrower and more tortuous. And let us just say for now that the length is the distance from the well to the point that the oil pressure is equal to the original pressure when the drill reached the rock. (We call that the **original pore pressure**.)

Now you might think that with the original 2,000 psi difference, that I used above, between the pore pressure and the well pressure that the oil would really gush from the well. And yes it might - but we don't want that and so we tighten the choke to reduce the difference in pressure between the well and the pore pressure, and the flow slows down.

However, as the flow of oil starts to move towards the well, it does not flow evenly through the rock. Think of watching rain hit a pile of freshly dumped earth. At first, as the rain falls it runs evenly over the surface. But as it does it finds some layers of soil are weaker, and others have been compacted a bit more. And so the water erodes the softer, less compacted soil, and the water near those channels finds it easier to flow into them. And so after a while the water coming off the pile is no longer evenly flowing but is cutting grooves in the soil and all the water is coming out of those channels.

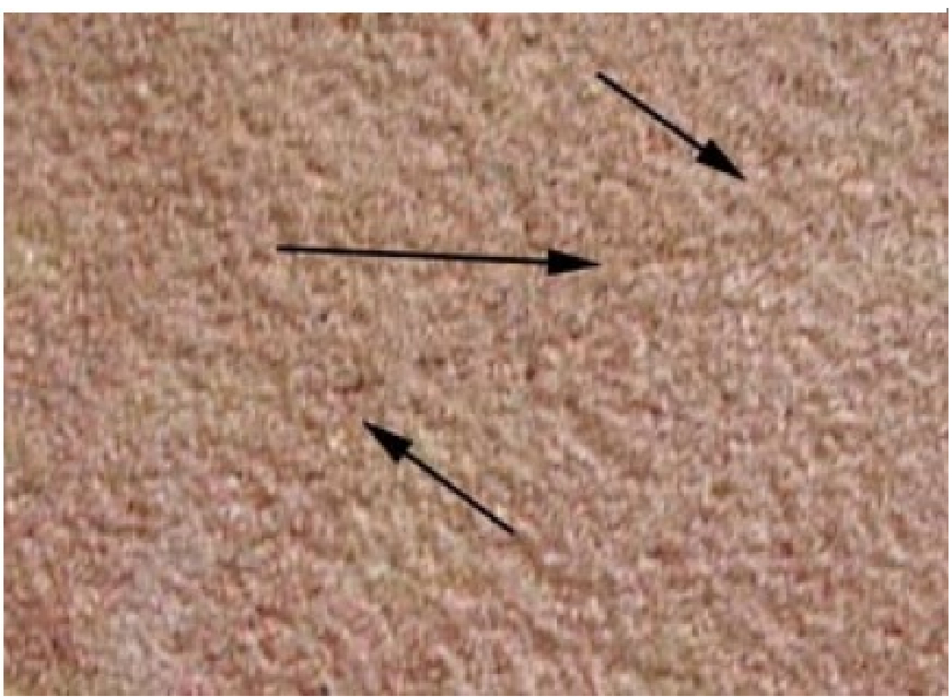
Rain on a tilled field in Iowa - note that the rain is already starting to cut channels.

In many ways the rock carrying the oil acts the same way. The two channels in the top picture are in the same rock, with the same oil, but it is much easier for oil to flow through the bigger channel, and it will be at much less pressure drop than it takes to get oil to flow out of the thinner crack. And with the flow of the oil the channels in which it does flow well get bigger, reducing further the flow through the narrow channels, and trapping, or **stranding** the oil that is left in them.



Piece of sandstone, showing the grains

Now you might think that this has, initially to be a great difference. Well, here is a picture of a piece of sandstone I had in my office. It is at first glance made up of grains of about the same size and were it full of oil you might think that oil would flow evenly through it. (It has no oil in it--oily rock looks black and it is hard to make out the features I am talking about due to lack of contrast.)



But if you look more closely (and I have zoomed in a bit on one area above the 6-inch marker) you might see a thin connected path wandering through the sandstone. (I have marked it with arrows.)

That line is one of higher permeability. I have been on a site where the ground was supposed to be as evenly sized and permeable as this sandstone, if not more. A test was being run in which my hosts had pumped some fluid into the rock. Since they did not get the result they wanted, they dyed the next batch of water a bright color and pumped it into the ground. They then dug a hole over the site, and looked down the side to see the thick colored layer that they expected to find. They needed a magnifying glass, all the fluid (hundreds of gallons) had gone into a single flaw, about the size of the one shown in the two pictures, and none anywhere else.

For those who can't see it very well, here is a picture of a block of sandstone outside the Oil Museum in Stavanger that I took this afternoon, and you should be able to see a number of larger fractures that have been naturally recemented running through the block)

However, while we were injecting fluid in the case just above, the opposite can happen if one is not careful in drawing the oil from a well. The initial production can create flow paths through the rock, leaving isolated patches of oil that are not recovered on either side.

But hold-on you say surely if we just keep dropping the pressure (by opening the choke) then eventually we will have enough difference to move even that oil. Well, No! (You may have noticed I am becoming a relatively negative person.)

I was reading "The Color of Oil" by Michael Economides and Ronald Oligney when I first drafted this post. It is a very fast (even more so than this) spin around the world of oil, but I am going to use their numbers (page 32-33) for this next bit.

The oil inside the pores of the rock is initially assumed, for now, to be at the same pressure as the burial depth of the rock (due to geological movement this is a very, very simplifying assumption, but let's make it). But as we let the oil flow out of the rock this pressure, which is caused by the oil and rock compression will get less. While the oil can expand and flow, the rock does not, and so after a while there is no pressure difference between the oil and the fluid in the well. The oil stops moving because the differential pressure has gone away. Professor Economides

> "Recovery of 3 percent or less of the initial oil in place can make the reservoir pressure equal to the pressure at the bottom of the hole. When this occurs, fluids are no linger

> driven into the well and 97% of the original oil is left "in place" in the reservoir. This defines primary recovery, the most elemental but generally unacceptable ending point in petroleum exploitation."

What else can we use as a driving force? Well, some posts back I mentioned the analogy of a bottle of champagne. Shake it, pop the cork, and the dissolved gas in the wine will fountain it out over the happy celebrants. But after the fizz is gone, there will still be some wine in the bottle. It is the same sort of thing that happens with the oil. Oil usually contains gas dissolved within it. As the pressure within the oil drops, this gas begins to come out of the liquid. (Slowly release the cap on a bottle of soda water and you will see the same thing.) (Note that this does not change the pressure in the well, and thus reduces the difference or driving pressure moving the fluid to the well.)

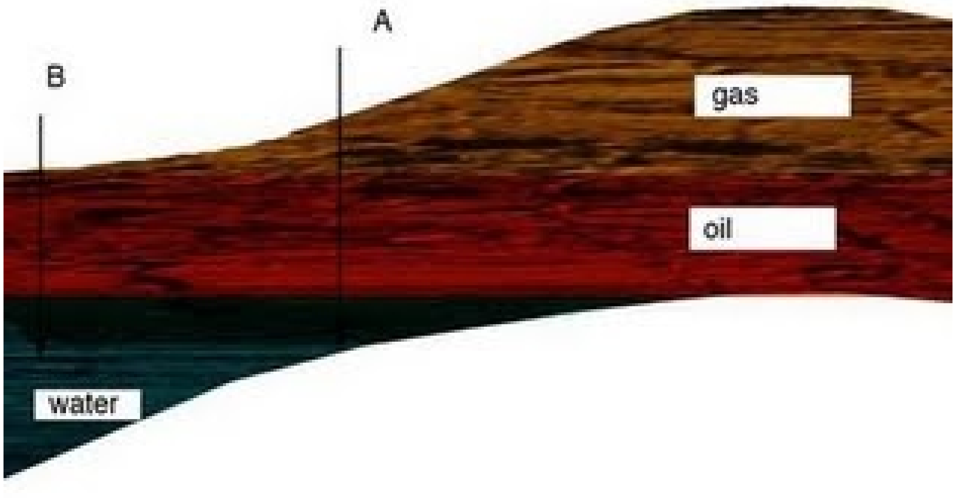
Professor Economides continues:

> "A specific (lower) pressure level called the "bubble-point" pressure marks the onset of natural gas evolution, known as the solution gas. When this level is reached (the point at which this occurs depends on the specific crude), recovery can increase substantially to 15% or more."

Now let's go back to our example of the two bottom layers of oil in the top sketch. The bottom one will flow oil faster and draw oil from further out, than the upper one. As the pressure in the larger channel drops, as it empties, the remaining oil in the channel will start emitting gas. While the gas will rise, overall, to give a gas layer above the oil, it will also flow more easily into the well than the oil in thinner channels. If the reservoir engineer is not careful at this point, all of a sudden he may find that all he is getting out of the well is gas. (Take a drinking straw and sucking gently move it down onto the top of water in a glass. Note that the straw has to be in the water before you can drink any. If you had machine strength suction and you don't so **DO NOT TRY**, you would find that if the straw was within half an inch of the water you might start to get a little, but effectively you won't get much.) So it is with the oil well. You need to be drawing from the oil zone only to keep oil production happening.

However, going back to Darcy's Law (in itself an application of Newton's Law) as the well has produced the oil and the compression has come off the oil as some of it left, the pore pressure in the rock has gone down, and thus the difference in pressure between the well and the rock is less. With less of a “push” the flow of oil from the well will also get less, and with no further stimulus, the oil flow will gradually stop as the difference between the pressure in the rock and in the well reached the same level, and if this were all that happened then it would leave about 85% of the well in the ground, and sometimes that does occur.

However, if you remember from the first post where I talked about rock pressure, there can often be water under the oil.



Simplified sketch of an oil bearing layer in the ground.

This water can provide some pressure on the oil above it, and as the oil flows up into the well, the water can rise up into the pore spaces that the oil has left, and keep some of the pressure on the oil a little longer.

Professor Economides:

> "If a large water aquifer is in contact with the petroleum reservoir, a natural drive mechanism can be provided by natural water influx. The larger the aquifer, the more effective and the more long-lived this drive mechanism tends to be. If a strong water drive is in effect, 10 to 25% of the oil in place can be recovered."

Once that is over, and with 25 - 40% of the oil recovered, then in a conventional well the oil is at the same pressure as the fluid in the bottom of the well, and no more oil will flow. To get the rest out will require some form of pumping.

And yes, one of the ways to increase the production is to pump water, under pressure, below the oil level to keep the pressure up. But to discuss that, and other steps in enhanced oil recovery are topics for another day.

But for now remember, it is not the oil in the reservoir that has been depleted, at this point, it is the force (the differential pressure between the oil and the well) that has been reduced, and finally gone away, and with it the oil production.

Unfortunately because driving pressure and permeability are so inter-twined this has been a long post. And yet I still may have glossed over some points too rapidly. So as usual if there are questions or discussion or correction, please comment.