The Oil Drum
DISCUSSIONS ABOUT ENERGY AND OUR FUTURE

The life of an oil reservoir

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Topic: Supply/Production
Tags: depletion, horizontal wells, oil production, water flood [list all tags]

With your indulgence I am going to try and explain a little bit more about some of the stages that an oil reservoir might go through, to clarify some of the topics that have arisen in discussing oil production from large oil reservoirs. To do this I am going to build a simple model, to try and illustrate the odd point, concerning production and reservoir collapse. (This might help in understanding some of the debate between Matt Simmons and Jim Jarrell, as reported by Marco. Please bear in mind that this is a very simplified example, to illustrate the points - to those more knowledgeable, I apologize. But please jump in and clarify what I have not made clear or not explained correctly.)

Let me start by assuming that I have a layer of rock that is 300 ft thick, five miles wide and thirty miles long. Let us then assume that this has been folded in the middle, so that it now has trapped oil within all the pores of the rock. And, for the sake of discussion let's assume that it has a porosity of 20%. Now having found this reservoir - which is, let's say some 6,500 ft below the current surface of the ground - back some years ago, the oil moguls of the time decided to drill into it and extract the oil.

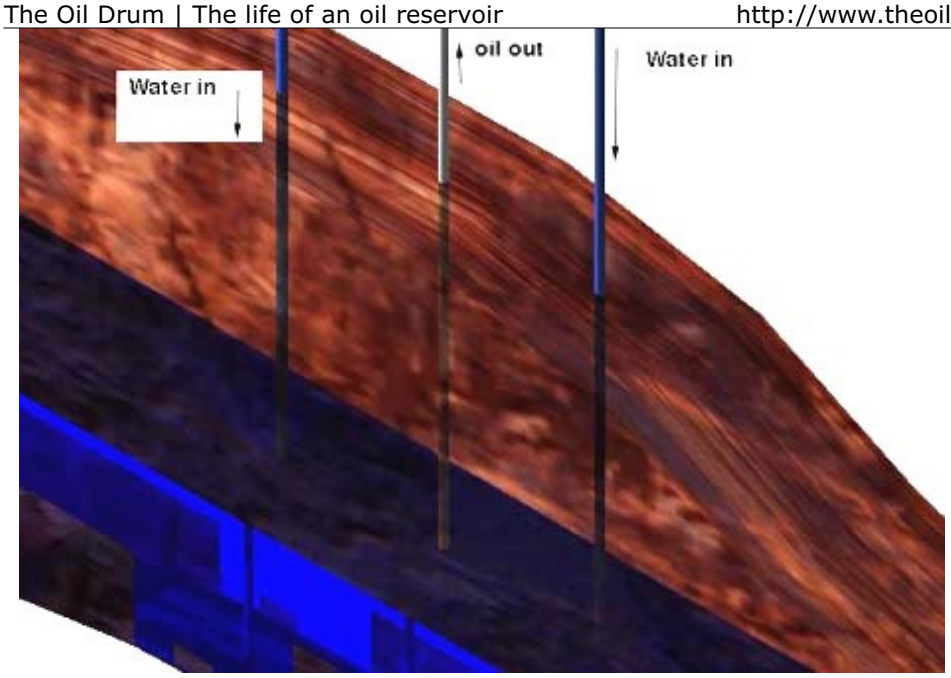
So first let's do a bit of arithmetic - 300 x 5 x 5280 x 30 x 5280 = 1,254,528,000,000 cu.ft. At 20% porosity, this means that some 250,905,600,000 cu. ft. are not rock, and in this case are going to be full of oil. This is equivalent to 1,876,773,888,000 gallons or 44,685,092,571 barrels of oil. This is, roughly 45 billion barrels of oil. That's how much is there. This is a relatively light oil and flows through the cracks in the rock quite easily, and there are a lot of these fractures, and it doesn't stick to the rock that tightly, so they can get out some 50% of the original oil in place. So, at this point we can say that the ultimate resource recovery (URR) is going to be 22.5 billion barrels if they can get it all.

Now, this being some time ago, the first thing that our friends did was to drill some oil wells, and this being that long ago they drilled vertical wells one quarter of a mile apart. To make life easier I am now going to consider just a one-quarter-mile section of the reservoir, taken along the length. We assume that the wells are spaced quarter of a mile apart, and that they gave us this one slice. If the slice is 5 miles long, then it has 20 wells set along the section, so that each well will pull the oil out of a box that extends out one eighth of a mile laterally from the well, out toward the next. The total recoverable oil for each well is roughly 10 million barrels, or 30,000 barrels per foot of the oil well in the reservoir.

Showing location of wells quarter-mile apart and in a quarter-mile thick slice along the reservoir. The rock thickness is exaggerated and this is not to scale.

The rate at which the oil flows into the well is related to the difference in pressure between the oil in the rock, and the fluid in the well; the frictional resistance of the rock to the oil flow through it; and the length of the well that is exposed to the rock. Let us assume that the rock resistance remains the same and that production varies directly with changes in the pressure difference and the length of the exposure. And let us start by assuming that the well produces 3,000 barrels of oil a day. (i.e. 10 barrels per foot of well exposed to the rock). Then, in the course of a year the well will produce one million barrels of oil. Connect up the pipes, and away we go.

After five years we notice that the volume coming out of the well is not as much as it used to be, and when we check with the engineer he explains that, as we take the oil out of the ground, so the pressure in the oil reduces, and the flow slows down. Well, bless my bananas, and here we have just promised a new palace to one of the grandkids. So we have a chat with the lads and they tell us of this neat trick they have in Russia. If we pump water into the ground under the oil well, then the water will fill the holes left as the oil leaves, and we can keep the pressure in the oil up, and the oil flow will not drop as fast. So out we go to the site, and we drill secondary wells around the first set that had been put in, and now we pump water back into the ground around the well, and bring the pressure back up to the pressure that we started with. And from then on we are pumping water into the ground as fast, (and soon to tell faster) than we are taking the oil out.



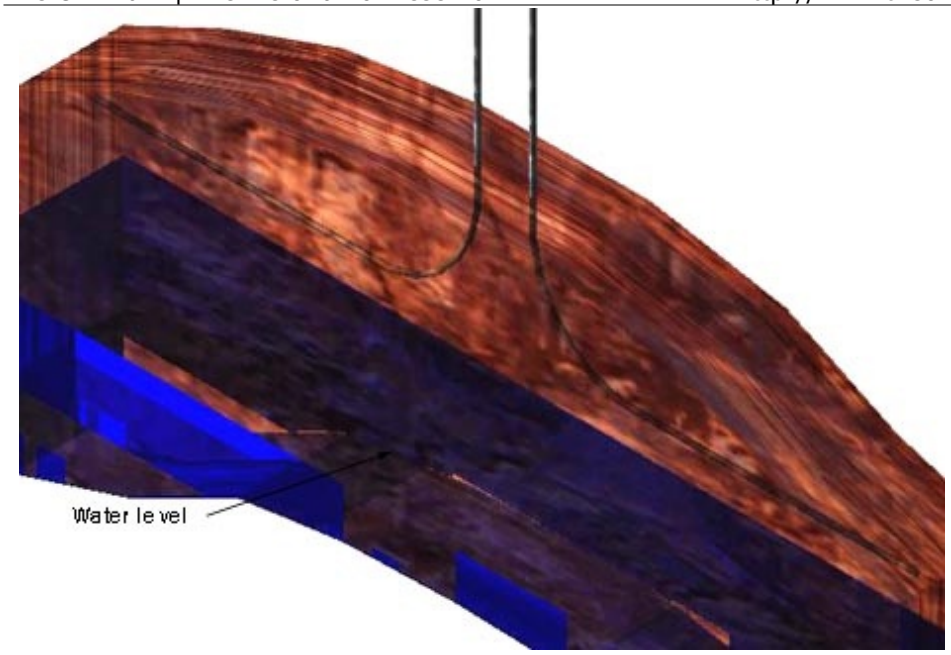
Initial pattern of water flood, adjacent wells flood under the producing central well

Because now there is a little problem that we hadn't thought of when we started this exercise. Over the years we have taken out say 4 million barrels, now as we compress the oil back to the original pressure (we're neglecting the gas issue for now) it will only occupy 60% of the original space, or the top 180 ft of the reservoir. Now at the same pressure we will only get 60% of our original flow, because the length of the well exposed to the rock has been reduced (and flow is related to length and pressure). And this is going to get worse, each year the flow will decline as the length of exposed well in the rock gets smaller.

For example, the next year it will produce at 1,800 bd,(10 barrels/day/ft) but at the end of that year we will have removed (simplifying) 650,000 bd of oil, and so the volume of oil will be reduced by (roughly) 11% of the 6 million barrels we started with, and so the following year the production will come from only 160 ft of the reservoir, and, at the same reservoir pressure, the flow will be reduced because of the shorter exposed length. And the flow will be, accordingly also reduced by 11%, assuming that the overall area remains the same. (Some folks might call this depletion, it is the decline in production with time).

Yikes, and here that palace isn't finished yet. So what can we do. Well it turns out that there is another trick we can pull out of the hat. Apparently some folk in Italy have found a way to turn a drill so that it drills horizontally across the reservoir, rather than vertically down through it. At the same time someone else has come up with this idea, that if you just pump the water in around the edges of the reservoir then it makes a more even lift of the water:oil surface up the well, and there isn't as much chance of water stopping the well from producing while there is still oil available. Bingo, we'll have a couple of those.

We only need two because we can now drill the wells horizontally all the way from the middle to near the edge of the reservoir (one in each direction). So the holes are each two-and-a-quarter miles long and are equal in exposed length to the reservoir of forty of the original wells. Now the length stays the same, but the production drops to 1.5 barrels/ft/day. But, by pumping water into the surrounding wells, we keep the pressure up and hold that production. So now, out of these horizontal wells we get say 18,000 barrels of oil a day. And it keeps pumping. Call the grandkids and have them build an extension on the palace.



Water flood under horizontal wells, in this ideal case the water is fed from the outside of the reservoir and rises as a steady horizontal lift over time - until it reaches the wells.

But wait. When we started doing this, we had taken out of the ground about half of the recoverable oil. We had, in that slice of the reservoir some 200 million barrels of oil. We had produced half of it, and thus had 100 million barrels left. We are now producing it at the rate of 13 million barrels a year (2 wells). But it just keeps pumping, as long as we keep pumping that water in, until . . . . . .the day the water level reaches the horizontal well layer. And we're done, it's all over. Oh, there will be some indications before it happens, water cut will start to rise again, and production drops and this is really an idealized case and production will likely drop before then due to preferential water flow through the ground. But in either case, even if we get all that was there, and we won't, we didn't create any more oil by drilling horizontally, we just got it out faster.

Hmmm! Anyone want to buy a beautiful palace, going cheap, nice view of the Gulf. Peaceful neighbors!

There is one final thought. Our friendly moguls, who gave us that slice, set up the field so that while our slice was producing 60,000 bd, they had another 30 slices, or 7.5 miles of the length of the field also producing, giving them an overall production of 1.8 million barrels a day. After a while they noticed, overall, that the field was dropping in production by 8% a year (they were paying closer attention). To overcome this they just started production in another couple of slices, drilling another 40 wells to make up the drop that year. And so they continue to do this, adding half a mile a year to the length of the reservoir from which they are producing, until, after 45 years, they run out of reservoir to drill in. And in the distance they hear a rather large, rotund lady starting to sing something about "dark, satanic mills".