The Oil Drum
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Reserves and Production: A Simple Example (based on Abqaiq in Saudi Arabia)

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Topic: Supply/Production
Tags: abqaiq, oil production, tech talk, water flood [list all tags]

So far in this series of technical talks, I have tried to explain some of the pieces that have to be put together to get crude oil or natural gas out of the ground. I intend to go on with the series in the coming weeks, but thought that today I would put some of the different thoughts that I have talked about recently together. So I am going to talk a little about reserve calculations and production and will use an example to show how the numbers are derived. And again, let me stress that this is a very simplified example. It is also only somewhat fictionalized, as I shall comment at the end.

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. (We're neglecting, for now any water that is also in the rock).

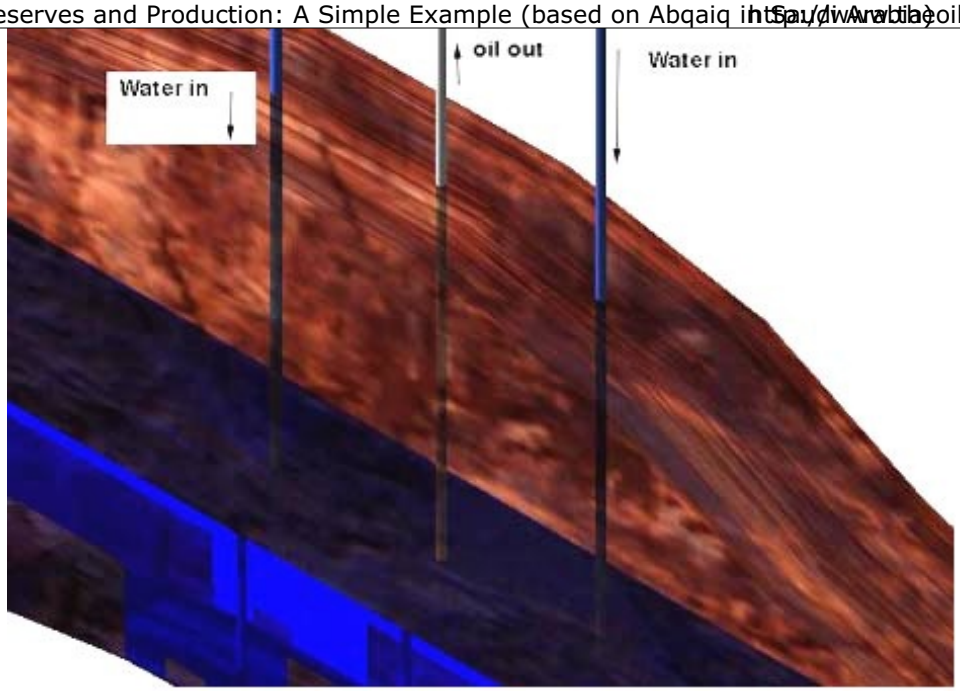
This is a relatively light oil and flows through the cracks in the rock quite easily, and there are a lot of these fractures, and it doesn't stick to the rock that tightly, so the assumption is made that production can get out some 50% of the original oil in place. So, at this point we can say that the 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.



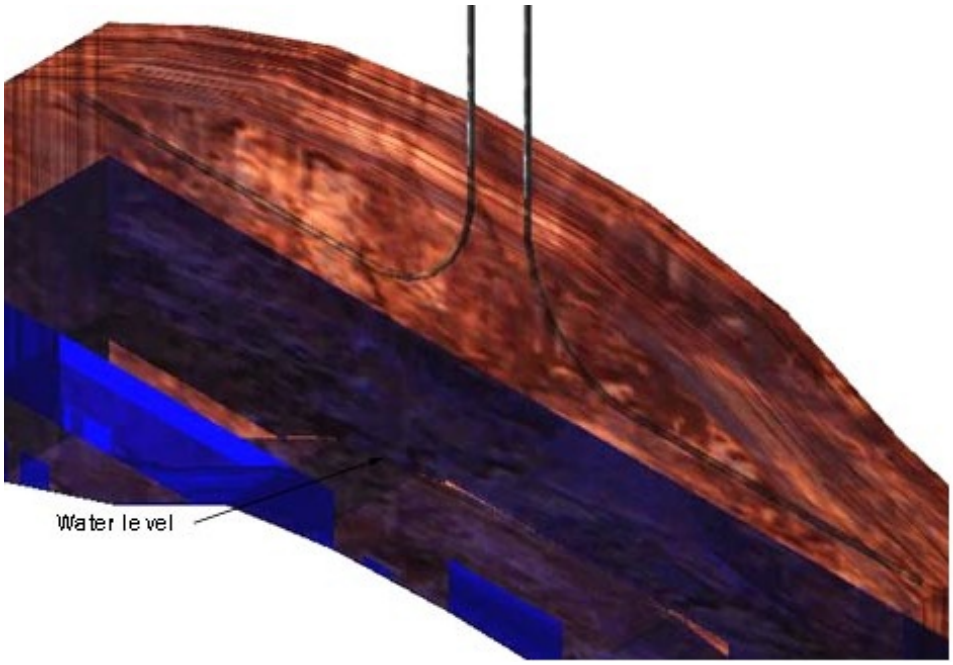
Initial pattern of water flood, adjacent wells flood under the producing central well

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.

As the technology improved, over the life of the field, it was found that oil also occurred in an additional mile of rock to either side of the zone that had been initially expected to hold it. It also turned out that the field extended about 7 miles longer than originally anticipated. However, with the new additions and as the field finally began to play out it turned out that the average thickness of the carbonate grainstone was only 240 ft. If you do the same calculation as before you will find that this changes the initial estimate of the original oil in place to be some 62 billion barrels. This change in reserves as the field is developed is not uncommon in oil fields and is one of the ways in which reserves grow, often quite significantly after the field has started to be developed.

And at this point those of you that have read "Twilight in the Desert", or have worked in the oil patch may note that what I have used for my numbers bears a reasonable similarity to the oilfield known as Abqaiq in Saudi Arabia.

Google Earth image showing Abqaiq relative to the Saudi coastline (the blue dot where the roads meet)

(Although all the exemplary numbers other than the geometric size of the field, and its porosity and depth were made up by me as I went along to illustrate the developments of the technology that have been applied to that field.) The oil has a 36 deg API, with a gas/oil ratio of 860 cf/barrel. (It is also sour). The rock permeability is 400 millidarcies in the Arab D formation (this info is from "Twilight"). We can get some other information on this field from a number of other places. So, as a contrast between the myth and the reality you might want to read on.

The first well at Abqaiq was spudded in August 1940. It began production at 9,720 bd in October 1940, but had to be temporarily shut-in the following February because of the adjacent war. Early development was slow, but began to pick up as the conflict moved further away.

> If the expansion of 1936 had struck some of them as a period of hectic confusion, this 1944 expansion struck them as bedlam. Their goal by the end of 1945, they were told from San Francisco, was 550,000 barrels a day, nearly 25 times what they were turning out now in their standby operation, and much more than the capacity of their existing wells. There would have to be a massive drilling program involving perhaps 20 strings of tools, and drilling that many oil wells meant developing adequate water supplies both at Abqaiq and at Qatif, where they had been instructed to put down a wildcat. . . . . By June 13th, too, Phil McConnell had entirely shut down the Abqaiq field after completing No. 5, and had diverted his entire Drilling Department to Ras Tanura.

By 1962 only 72 wells had been drilled in the field. At the same time the gas was being extracted with the oil, and 50% of it was being used. Most of it was pumped back underground to maintain pressure and in some cases it was mixed with LPG (Liquefied petroleum gas) and this helped dilute and increase the flow of oil from the reservoir. (But sometimes it did not work). It was used in the Ain Dar part of the Ghawar field and right next door to Abqaiq. But in 1982 the gas was collected for sale abroad.

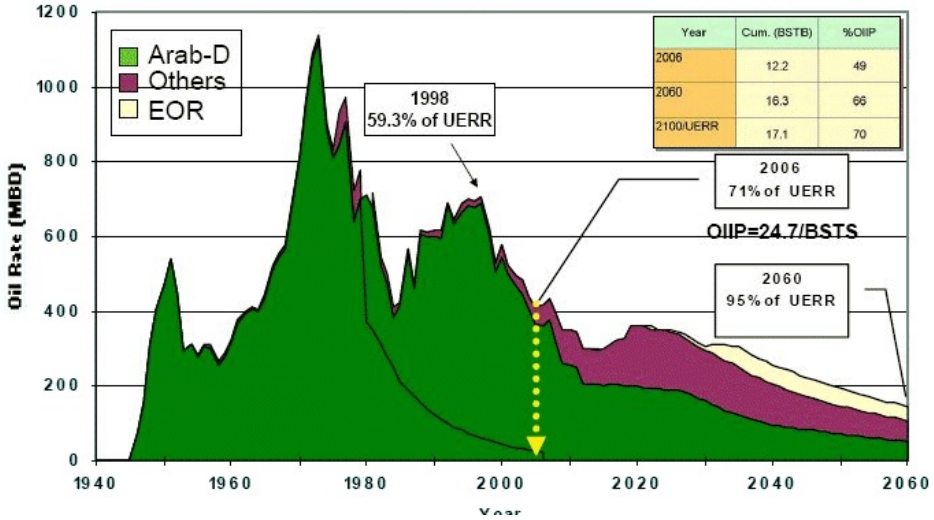
By 1972 Aramco was drilling a well at the rate of 1 every 2.1 days. Shortly thereafter Abqaiq peaked, at 1,094,062 bd. In the area of Abqaiq there were 4 drilling rigs and 5 workover drigs in the period around 1977, as the field fell back to a production of less than 800,000 bd. By 1981

production was down to 652,000 bd. In the mid-80's it was partially shut-in, and flow was reduced to 200,000 bd as demand declined.

And while the rest of Saudi production continued to grow, in 1988 it had 550 wells in production by 1990 Abqaig had only 47 flowing wells, and by 2002 had dropped to 500,000 bd. It is currently 73% depleted, according to Aramco in 2004 and 74% according to the EIA.

Now beyond this point there are some conflicting numbers. Let me just list some of the information that is out there.

In the 50 years since discovery it yielded 7.5 billion barrels of oil.

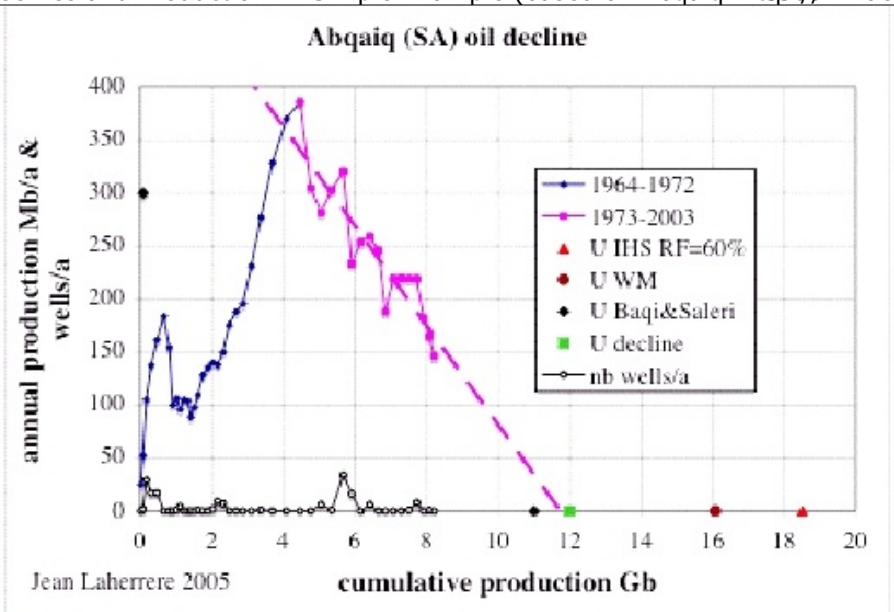


Abqaiq production history from Saleri via Joules Burn

The EIA considers that Abqaiq has 17 billion barrels of proven reserves. This is in contrast with the recent "World Energy Outlook 2005," which projected (through 2004) that Abqaiq had 5.5 billion barrels remaining and had produced some 13 billion. (But it got the start date wrong as well.) It uses IHS data for its projections.

From that data, quoted by Jean Laherrere, one can estimate the total oil contained in the field. Using their anticipated total of 19 billion barrels, and that this is considered to have a recovery factor of 60% indicates that the overall oil in place is about 31 billion barrels. This is about half of the theoretical prediction I had made, using total volume and porosity, but given the variations in geology over the region, that the field has about 50% of the oil that the general assumption predicted is not bad.

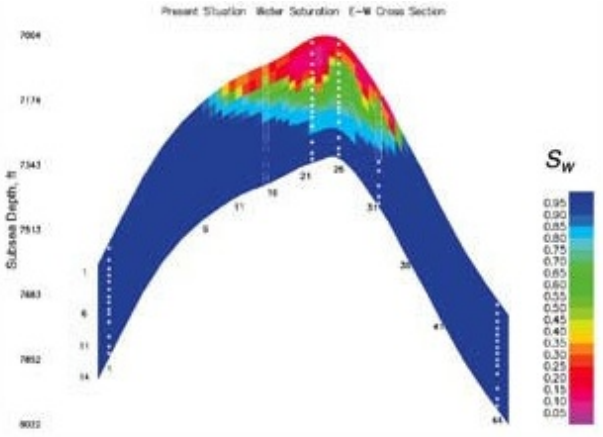
However using the Aramco statement that the field is 73% depleted implies that the total oil that can be recovered from the field is around 11 - 12 billion barrels, which is in line with the HL projection created by Laherrere.



Abqaiq production projection by Jean Laherrere

The field is variously currently reported as producing between 250,000 bd and 434,000 bd. The IEA consider the latter figure - which yields 158 million barrels a year, sustainable through 2010. (At 8% depletion, although Aramco are claiming that they are holding depletion below that - by continuing in-field drilling). However if the OIP is 31 billion and they are only able to recover 11.5 billion, then this gives a recovery factor of some 37%, which is a fair bit less than is derived by other approaches.

And, it was from this field that Dogru, Hamound and Barlow generated this image:



Section through the Abqaig oilfield

Joules Burn has provided a much more detailed discussion of Abqaiq in a post from May 2008 (and also repeated today above this post).

This has been a bit longer than these usually are, but has still had to make a lot of simplifying assumptions to fit, so again I ask those who know more to either bear with me, or to post comments.