The Oil Drum
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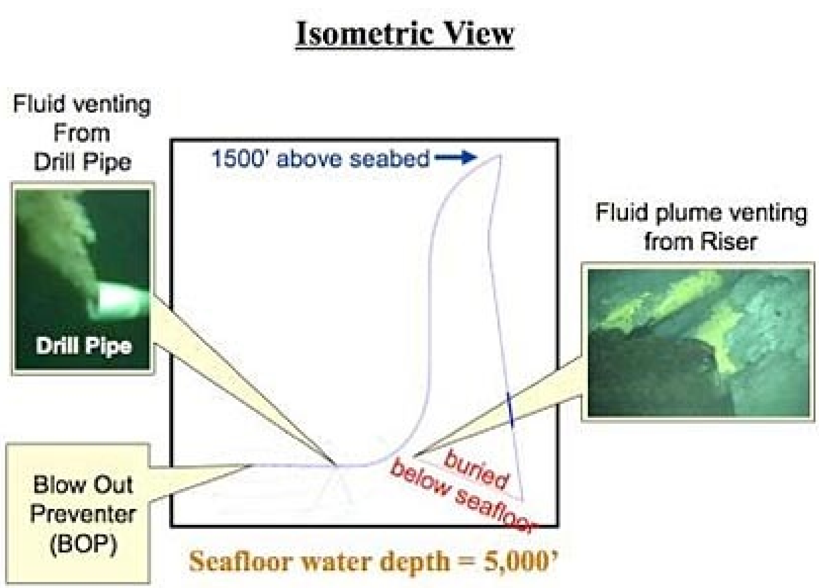
Tech Talk: Revisiting Oil Well Pressures and Blowout Preventers after BP's Gulf of Mexico Oil Spill

Posted by Heading Out on May 2, 2010 - 9:01am
Topic: Supply/Production
Tags: blowout preventer, deepwater horizon, leak, tech talk, well pressures [list all tags]

I thought that it might be useful to explain where and how at least part of the problem with the Transocean Deepwater Horizon fire and sinking spreading oil across the Gulf of Mexico might have started. I am going to start by repeating one of my previous technical posts, where I explain what a blow-out preventer is, then I will add some comments in an update relating to the current leak.



Pictures of the oil flows (Drillingahead)

This post is going to deal with some of the problems that a driller encounters as he reaches the layer of rock (the **reservoir**) in which the oil or gas is being held. And what I want to talk about is something called **Differential Pressure**, but to explain that, I need to drag you back to High School for just a minute.

Let's, in fact, go back to Newton's Three Laws. And, for those who slept through that part of the Physics class in school, don't be too ashamed - I have seen the desk where Newton whittled his name, being similarly bored. Let's start with the first law, which is probably the most relevant.

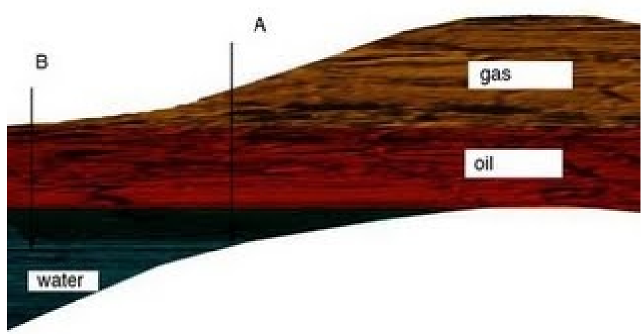
> Every object in a state of (rest or) uniform motion tends to remain in that state of (rest or) motion unless an external force is applied to it.

Except that I want to change external force into pressure (which is force divided by area) since it is the way we normally think of it. (Note: I added rest which is a special case of uniform motion since that is specific to the oil we want to talk about). In other words, nothing is going to move unless something pushes it. It is what does the pushing and what does the moving that this is all about.

And now our drill, is down through the casing, drilling the well open hole and using the circulating mud to carry away the cuttings as it continues to go deeper. I had stopped progress last week just before we went down to total depth (**TD**) of the well, or into the **pay**. And the reason I did has to do with this differential pressure. But first, the bit about how you calculate pressure.

As you go deeper into the earth, the rock at any layer is carrying the weight of all the rock vertically above it. For rough calculations we generally consider that this rock weighs 144 lb a cubic foot. So that 10 ft down the weight of the overlying column on a square foot would be 144 x 10 = 1,440 lb/sq ft. But through convention we reduce the area that we talk about to a square inch (144 sq in= 1 sq ft) so with this division the weight on a square inch would be 10 lb. A remarkable resemblance to the depth number (grin). This means that we can assume, as we go deeper into the earth, that the pressure on the rock increases by 1 lb/sq. inch (psi) for every foot we go deeper. This means that at 6,000 ft, the rock is under a pressure, from the rock above it, of 6,000 psi.

Now water does not weigh as much as rock, but can be approximated to roughly half the weight. So that, by the same argument, under water, for every foot of depth the pressure goes up roughly half-a-psi. So that at 6,000 ft under water the pressure is 3,000 psi (roughly twice the water pressure in the wand you use at a car wash). Now because we have increased the density of the fluid in the well (the mud) to help lift the cuttings out of the hole it weighs a bit more than water, but for the sake of working the example I'm going to use the half-psi measure for now. We are now at the point where the actual amount that it weighs becomes important.



Simplified sketch of an oil bearing layer in the ground.

I have made a very simple sketch of the layer of rock that we are going to drill into. In order to trap the oil it is shaped into a dome, and the sketch shows a vertical slice through that dome, viewed from the side. It has a layer of oil in it (the reddish layer), but above that is a layer of gas that has diffused from the oil (brownish), and below it is water (bluish) which may have been there when the algae died and which has stayed with the remains as they turned into oil under the temperatures and pressures deep in the rock. Oil floats on water, and gas is lighter than oil, so we have the three layers. At the moment the well has not arrived and all three fluids are sensibly in equilibrium at the same pressure.

Now why do we need to know this before we reach our layer of oil-bearing rock? Well first let's go and interpret that first law a little more.

If a person on either side of you pushed you with equal force at the same time, you don't move, because the two forces balance out. It is only if there is one force, or if one of the two pushes harder, that you move. In other words, where there are a number of forces acting on a body, it is the size of the **difference in pressures**, and the direction of that difference, that controls the movement.

Consider, here we are drilling merrily away (and have cased the well near the surface, and hit no more fluids on the way down) and at 6,000 ft. we penetrate the rock that is capping the well, and enter the rock with the oil in it. The oil (in the rock) is at some fraction of the overburden pressure, since it is trapped in the rock, and for the sake of this example I am going to say that it is at 5,000 psi , the fluid in the well is at 3,000 psi, the height of the mud column.

There is a difference of 2,000 psi. We are drilling a hole some 6-5/8th inches in diameter. That has an area of about 34.5 square inches. The total force we have suddenly applied to the bottom of the well (bit and fluid) is thus (area x pressure difference) 34.5 x 2,000 = 69,000 lb (or 35 tons). Oops!

Oil rig blowout in Turkmenistan (Energy Industry Photos)

Sadly most catch fire and the rig is destroyed (there are more pictures of such damage at the EIP site). It's called a **blow-out**, and they still happen.

This is why we approach the oil/gas producing zone of the rock with caution. And bear in mind that the driller that is controlling the progress of this well is at the surface, trying to guide the bit at the bottom of the hole, with, historically, little immediate information to help.

Based on the surveys that brought the crew to the site in the first place he knows roughly how thick the layers of rock are, and probably what rock they are, but the only real information on where the bit is in that sequence, is from the returns (cuttings) that come out of the well, and there is the lag, we mentioned before, while those chips make their way up the 6,000 ft pipe. (This is why **Measurement While Drilling** [**MWD**] has been such a relatively recent boon to the industry (though not all rigs have it)).

By monitoring a number of pressure gages the driller can gain a sense of what is happening at the bottom of the well. If he senses that there is going to be a problem, then he can do one of several things, based on the way the well is set up.

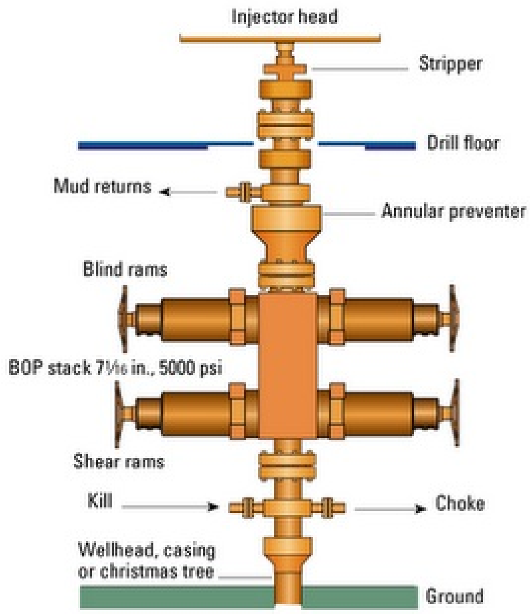
The first thing is to increase the density of the mud. By making the fluid in the well weigh more, the difference in the pressure across that face is reduced, and the change in conditions is easier to handle. However **weighting up the hole** has the disadvantage that it becomes much slower to drill with a heavier mud (it is a poor bottom-hole cleaner among other things). And, if done during drilling, bear in mind that once the heavier mud is added to the well it won't be fully effective until it has had time to get down to the bit and then fill back up the annulus between the drill string and the casing all the way to the surface.

So that is an expensive and slow option. Let us take the game a little more interesting and say that there is a gas pocket above the oil, and that the hole is going to go into the layer at A. Gas will enter the well at the down-hole pressure, but as the bubble rises, that pressure is reduced, and the gas expands, pushing the mud above it out ahead of itself. Another potential source for big-time trouble. And this one (which is known as a **kick** in the well) happens much faster, so there is less time to react.

How do we handle this? The answer is to invert the problem. Gas or oil flows into the well because the well is at a lower pressure than the fluid in the rock. The fluid in the well is, initially at the pressure created by the depth, and by the weight (density) of the mud in the hole. However, if we put a restriction on the flow of fluid out of the well (such as when you put your finger over the end of a garden hose so that the stream becomes smaller and shoots out further) we can increase the pressure in the well.

For those who want to know why, if the same volume has to go through a smaller hole in the same amount of time it has to go faster. This means it has to be pushed harder. **Bernoulli** explained it, and there is an animation available that helps explain it.

What it means is that by adjusting the flow out of the hole, the driller can adjust the internal pressure, and thus "**kill the kick**," or if gets to be too much of a problem, “**kill the well**”. But it is not completely that simple. Bear in mind that there is all the drilling and rotating equipment on the rig floor connected to the drill pipe at the top of the well. None of this can stand much pressure. So we need to place another piece of equipment between the drilling rig, and the top of the well.



Blow-out preventer (Schlumberger)

This is the Blow-out Preventer (BOP), which is essentially a ram that very rapidly shuts off fluid flow at the top of the well. These have to be well designed, since they are generally the line of last defense against a blowout, and when they fail as the pictures show, serious problems arise. They also form the basis for the well-known structures, often referred to as **Christmas Trees** that sit at the top of producing wells. By themselves, however, these aren't enough, since their main function is just to slam the door shut, before all the oil gets out and we have a gusher.

The more critical tools are the **chokes** on the well. (Below the rams in the picture above). There are generally several, both hydraulically operated and manual (in case the power dies) which are simply large valves that can be turned to increase or reduce the size of the flow path out of the well over to the mud pits. By adjusting these, in real time, the driller can control the well pressure, and thus the dynamics of the behavior at the bottom of the well. And after the rig leaves, an operator can adjust well pressure, and thereby the production from the well and its long-term performance.

If the operator is well trained (and you find drilling simulator equipment in Petroleum Engineering Departments so that students can understand how to do this (I last tried some decades ago) the well pressure will be controlled, so that any kicks can be handled, and the drill can now penetrate safely into the rock containing the oil/gas, which we call the **reservoir**, or the pay.

Update

The oil spill is continuing to get worse, and there are growing questions that have been raised on what could have gone wrong, and how it can be fixed. I am in the same position as most, in regard to getting information – it comes from news reports, in the main. But there are some points that can be picked out as the focus of those reports switch to the impact that the oil is going to have on the coast and businesses that are going to be severely damaged.

An early story noted that the BOP had recently been tested.

> Mr. Hayward said the blowout preventer was tested 10 days ago and worked. He said a valve must be partly closed, otherwise the spillage would be worse.
>
> There are a number of things that can go wrong with a blowout preventer, said Greg McCormack, director of the Petroleum Extension Service at the University of Texas, which provides training for the industry.
>
> The pressure of the oil coming from below might be so great that the valves cannot make an adequate seal. Or in the case of a shear ram, which is designed to cut through the drill pipe itself and seal it off, it might have encountered a tool joint, the thicker, threaded area where two lengths of drilling pipe are joined.
>
> Still, Mr. McCormack said, "something is working there because you wouldn't have such a relatively small flow of oil." If the blowout preventer were completely inoperable, he said, the flow would be "orders of magnitude" greater.

However oil is now flowing through the BOP and out into the water immediately above the well site on the sea bed. When the site was visited by a small remotely operated vehicle with cameras they showed that the riser, the pipe that normally carries the oil from the sea bed to the surface, had kinked over when the rig sank, and oil was coming from three places:

> The Coast Guard said it had not detected oil coming from the well Friday and assumed post-accident efforts to activate the blowout preventer "a huge stack of valves sitting atop the wellhead on the sea floor" had been successful.
>
> But later trips by the remotely operated vehicles (ROV's), discovered oil shooting from the end of the pipe-like riser that had connected the rig to the blowout preventer.
>
> A second, smaller leak was found in a section of drill pipe near the wellhead. That 21-inch-diameter riser had become detached from the rig when it sank. In the process, it was folded over at a 90-degree angle just above the wellhead, which had the effect of kinking it like a garden hose and constraining the flow of oil from the well. It now sits in a long, meandering mess on the ocean bottom. This helps explains why oil was not initially thought to be seeping. , . .
>
> The preferred option, he said, is still to find a way to engage the blowout preventer. That fix, if it works, could be handled in a matter of days, he said.
>
> But if that doesn't work, the other option is to drill a deep "relief" well into the damaged well and stem the flow of oil, though that option could take several months, Suttles acknowledged. He said his team would spend the next several days trying to determine the best method.

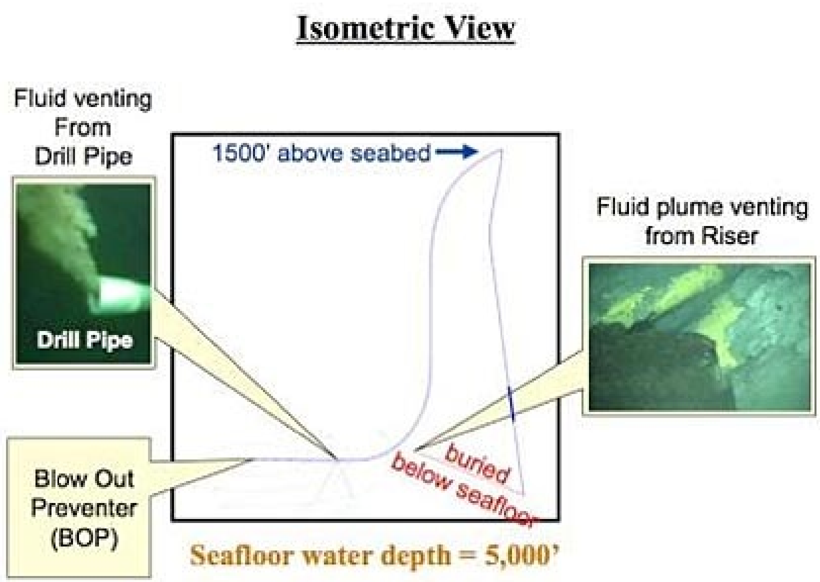
The problem lies, in part, with the capabilities of the ROVs and their ability to get access to the well site on the sea-bed.

There is a report from a survivor (h/t Fractional Flow) that says that the well was shut in and they were going through the process of separating the rig from the well, and moving it off. They began by cleaning out the drilling mud from the riser, replacing it with sea water. However, when they re-opened the valves at the top of the well, the pipe in the well had become filled with gas from the well, under considerable pressure, and this "Kicked" the well as the valve opened. Gas, as the pressure gets less as it moves up the pipe, expands much more than oil. And unfortunately in the process of disconnection, the pressure to hold the gas, which comes from the density of the drilling mud in the riser initially, had been removed as part of the disconnection process.

So the high pressure gas was able to blow all the sea water in the riser out onto the deck of the rig. (This happens extremely quickly, well below a minute) The gas then followed, and as it flowed out of the pipe at the top of the well there was some hot source that caused it to ignite. (This could even be from a static electricity spark). Because of the depth of the well, the pressure in the bottom of the well was in the 30-40,000 psi range.

Part of the problem that arises with flows at that pressure is that any abrasive particles (such as small pieces of rock) will cut through metal at the speeds at which it is carried. (Such jets were used to remove the damaged tops of the wells in Kuwait after the Gulf War, for example). So that it is possible that as the BOP started to function the high-velocity flow may have eroded part of the system to allow some fluid to bypass the plug that the BOP inserted. If that happened then the continued flow would just enlarge the passage again fairly quickly, so that the BOP will become ineffective.

However there are pictures of the leaks available.



Pictures of the oil flows (Drillingahead)

At this stage there does not appear to be that great a driving pressure for the oil coming out of the well. (If there were, the flow would be more directed horizontally) This suggests that the BOP did at least partially function, and that the passage may have been eroded by the particles in the gas and oil now escaping.

There is a recent report that the accident may have been caused by a poor cementing job by Haliburton:

> After an exploration well is drilled, cement slurry is pumped through a steel pipe or

> casing and out through a check valve at the bottom of the casing. It then travels up the outside of the pipe, sheathing the part of the pipe surrounded by the oil and gas zone. When the cement hardens, it is supposed to prevent oil or gas from leaking into adjacent zones along the pipe.

> As the cement sets, the check valve at the end of the casing prevents any material from flowing back up the pipe. The zone is thus isolated until the company is ready to start production.
>
> The process is tricky. A 2007 study by the U.S. Minerals Management Service found that cementing was the single most-important factor in 18 of 39 well blowouts in the Gulf of Mexico over a 14-year period. But at the time of the accident, "well operations had not yet reached the point requiring the placement of the final cement plug, which would enable the planned temporary abandonment of the well," the Halliburton statement said.

However it is hard to see from what is known, that this was a cause in this case.

Some other earlier Tech Talk posts that might be of interest in following the ongoing discussion about the problems encountered include:

Casing a Well
The Drilling Part of Creating an Oil Well
Completing and Perforating a Well