Aerial view of the mud gushing out of the Lapindo Brantas well (© Greenpeace/Vinai Dithajohn).

The Pressure Beneath

The recent events at BP's Macondo well in the Gulf of Mexico have highlighted the inherent dangers in drilling wells in increasingly hostile environments, and have brought worldwide focus on the regulations governing the petroleum sector and the measures companies are taking to prevent a 'worst case scenario'.

In Australia, the Montara Commission of Inquiry delivered its final report into the circumstances surrounding the well leak from the Montara wellhead platform in the Timor Sea to Martin Ferguson, the Minister for Resources and Energy, towards the end of June. The report has yet to be publicly released pending legal considerations.

PESA News recently talked with Richard Swarbrick, Managing Director of GeoPressure Technology, an Ikon Science company, and Steve Jenkins, GeoPressure Operations Manager, about some of the issues associated with subsurface pressures and well integrity.

GeoPressure, a UK-based company founded in 1997, provides a range of pressure training and consultancy services, including software designed to manage and visualise pressure data.

Swarbrick, who holds a geology PhD and who has extensive experience in both the private sector and academia going back to 1979, said there are different methods for defining high pressure.

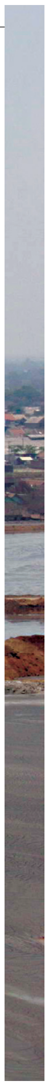
"There are two ways of considering high pressure when planning wells. High pressure can be considered the ability to drill through the 'window' between the pore pressure and the fracture gradient. This narrow drilling window can occur at any depth, but is often located below 1 to 2 km. When the pore fluid pressure is well above normal it creates a narrow drilling window between the pore pressure in the formation and the fracture pressure. To drill through this window requires careful monitoring and control of the mud system, and the mud weight cannot exceed the fracture at the last casing point.

"An alternative way, sometimes used for describing high pressure, is to hardwire a number. So, the number might be, for example, 10,000 psi. In Europe, the HPHT [high pressure, high temperature] environment requiring additional well planning consideration would be wherever the subsurface pressure was higher than 10,000 psi and high temperature above about 150°C."

Swarbrick said it is important for operators to understand the geological context for high pressure reservoirs that are being drilled for oil and gas.

"High pressure is there for a reason, something has caused it to be there", he said. "So we have to understand what the sedimentation rate is, how fast sediment has been accumulating, because that influences the pressure in the sense that as rocks get buried they get compacted … and to do that they have to get rid of some of the fluid and the porosity goes down.

"The fluid in the pores has to escape upwards, mainly towards the surface, through the rock column. If the rocks are deposited very fast, and the rock's got what we call a low permeability, an inability to allow that water to pass through, then it will store that water, and that water will then assume some of the weight of the rocks



that are being deposited on top—and that's one of the predominant reasons why we have high pressure.

"Some of the other reasons why we have high pressure in the subsurface relate to things like oil and gas generation; particularly gas generation, because gas wants to occupy a bigger space, and so as a consequence of that it pushes up the pressure locally where that's happening, but then that starts to redistribute itself.

"And there are also all sorts of rock framework changes that take place as you get to higher temperatures, where the rocks start to get weaker, and so that compromises the pore space, and that then puts more weight on the fluid and puts the pressure up …

"What we do, pre-drill, is to start off by saying, 'What's the context? And what sort of pressures might we anticipate as a result of those mechanisms?' What we then do is we say, 'What sort of data have we got which can corroborate any of our ideas about what the pressures might be?'"

Swarbrick said methods for collecting pre-drill data are dependent on the area being drilled, with frontier areas heavily reliant on seismic interpretation.

"Imagine you're in an area which has never, ever been drilled. What data might be available for a pre-drill pressure analysis? The only data available are remote data, which is either gravity data or seismic data, and seismic data tend to be much more important", he said.

"If you move from a true frontier area to an area where quite a lot of wells have been drilled, you increase your ability to predict with confidence, as your knowledge and confidence is built by knowing what the rocks are and being able to test the pressures in any of those wells that have been drilled …

"In terms of saying how confident we are, it just depends on what amount of information we've got from either surrounding wells, or, if you don't have any wells, what's the quality of the seismic data we're using?"

Swarbrick said, once borehole data have been collected, it is important to relate that information to the seismic response. Additionally, there may be direct measurements of pressure in the reservoir, important calibration for the non-reservoir section.

"Unfortunately, the reservoir is a smaller proportion of the total rock column than the non-reservoir. In the non-reservoir we can't measure the pressure. We can only estimate it. So, we go back to using relationships, using rules of thumb, using analytical relationships in computer programs, to try and work out what the pressure is from seismic and drilling data combined.

"Non-reservoir rocks comprise the majority of the section that we drill, and that's also true 'while drilling'. Drilling through the non-reservoir section we try and get a sense of what the pressure might be if we drill into the reservoir. Reaching a reservoir with a mud pressure too low will be dangerous, causing a 'kick'—so, reading the signs in the non-reservoir rocks is critical to good well drilling practice."

Swarbrick noted the evolution of gas, the background gas being returned in the mud, is an important indicator of pressure.

"There's often ambiguity", he said. "But an increase in gas can also be an indication of the fact that the mud pressure is not high enough to hold back the formation pressure in a reservoir. This gas increase would be an early sign of problems ahead if not corrected.

"A lot of people don't appreciate that drilling in non-reservoir rocks, you're just looking for subtle indications of the relationship between the mud pressure and whether it can hold back the formation pressure. Until you suddenly arrive into the reservoir, but if you haven't spotted those things as you've been drilling, then you're suddenly going to have something called a 'kick', which you've got to handle and handle fast."

"There are a lot of parameters you can monitor whilst you're drilling. As pore pressure increases, the rate of penetration might increase, the drill cuttings may change in shape and size, parameters like the torque on the drill bit may also vary too", Jenkins added.

Swarbrick said it is important that monitoring continues throughout the lifespan of the well.

"I think the recent experience in the Gulf of Mexico indicates just how important it is to monitor pressures until the well has been successfully abandoned", he said. "The pressure and the challenge of that high pressure remain there until the well has been satisfactorily secured."

Swarbrick said in the event of a 'kick' formation fluid is moving into the borehole and displacing the mud which is pushed out at the top by lower density fluid.

"The first indication of a kick is that you're receiving more mud back than you're pumping in, in which case, of course, you must be receiving extra fluid from somewhere else, and that's the interpretation that's made … coming probably from somewhere near the bit", he said.

"There's a number of operational things to consider: one is that you want to increase the mud weight to hold back the pressure and extra heavy mud has to be pumped down. But how heavy?

"Sometimes heavy mud can be pumped in straight away. Sometimes it is necessary to shut in and monitor the well. And by shutting the well in and monitoring the well, you're allowing an interpretation to be made of exactly what the pressure is where the influx is happening … and what mud weight is going to be required to 'kill' the well.

"However, there can be some dangers when shutting in a well; you're building up pressure all the way up through your borehole, and, of course, what you're concerned about is that the pressure is not so high that it would create a fracture and that fluid would then leak out of the borehole into the rocks.

"That's what happened in East Java. The Lusi mud volcano was created, in our opinion, because Lapindo Brantas, the well operator, shut the well in after a kick, the pressure built up, fractured outside the borehole wall, because there wasn't casing for a considerable depth above where they were drilling, then it just leaked to the surface. And the danger there, of course, is that you've completely lost control. There is no way of going back and stopping that because you've now got a fracture propagated all the way to the surface. In this case the high pressure water mixing with mud on its way to the surface has flooded a wide area, buried villages, and displaced 30,000 people.

"We have different methods of dealing with kicks", Jenkins added. "It will all be down to company policy, but the simple basics are that you shut the well in, you monitor it, you find out what the subsurface pressures are. Then you design a new drilling mud weight that will balance the column of mud against the pore pressure and bring the well back under control. As Richard said, that's got to be done in a controlled fashion."

Jenkins noted well integrity includes a number of issues.

"The one we've discussed already is the balance between the pressure exerted by the drilling fluid balanced against the formation pressure. Another element that's important is the borehole wall and it's stability, and that to some extent is dictated by the mud again, the mud chemistry, mud rheology and the mud weight.

"Another element is the invasion of mud fluids and the loss of mud into the formation. We also need to consider the well equipment, like the casing, the cement behind the casing, and the integrity of the casing shoe. In addition, moving further up the well, the well control system and the blowout preventer are also part of the well integrity. Finally, the monitoring system for measuring all the drilling parameters helps the drilling team infer what's going on in the well. They are all components of the overall well integrity."

Swarbrick noted all these components have to be designed prior to drilling.

"We go back to the fact that all of the decisions made in relation to equipment … the drilling design of the well, the positions of the casing and so on, are all determined prior to drilling, based on expected pressures, both the formation and fracture pressure. Some of those decisions may have to be considered in relation to the actual drilling experience.

"Imagine you've planned for a well to be drilled safely with a 14 pounds per gallon mud weight as a maximum. You've set your casing at the appropriate points and suddenly you get unexpectedly higher pressure at a shallower depth than you expected. Of course, the well plan has to be re-considered: will the casing still be placed optimally for safety and well integrity? Will extra casing be needed to reach the target? What are the new pressure predictions?"

Jenkins said early detection of an integrity breach often comes down to the mud logging system and monitoring of the drill mud.

"What's going into the well against what's coming out of the well? Is it balanced? Are we losing mud because we fractured the rock, or are we gaining mud because of influx?

"The drilling team will look at the drill cuttings and the gas that comes back in the mud. In addition, they will also look at the drilling parameters. On many modern rigs LWD, logging while drilling, methods monitor a range of geophysical and engineering parameters which indicate well integrity. The output of the LWD tools can be compared to the original well plan to provide an early warning of unexpected

Oil and gas developments are moving into ever more hostile environments.

changes that may be detrimental to the well integrity.

"I think, probably, in relation to the context of pressure management during drilling, the detection of increasing shale pressures is essential. If shale pressures are estimated during drilling, the drilling team can plan ahead before encountering high pressures in reservoir rocks. In this manner it is possible to avoid the difficulties caused by influxes of high pressure formation fluids.

"Mud gas may increase during drilling as the balance between the mud weight and formation pressure reduce. In addition, hole stability may become a problem. These are the principal early detections of an integrity breach in the sense of a formation pressure that's not being handled and controlled properly. An influx of formation fluids is referred to as a kick."

Swarbrick said the speed of reaction and response in the case of an integrity breach is critical.

"Time is of the essence here. Imagine for a moment that you've got an influx of fluid coming into the borehole—you're now replacing high density mud being lost to surface with low density material coming in from the formation, and so you're lightening the total mud weight designed to hold back the formation pressure. So, all the time they've got an influx, and you're not handling it or not recognising it, you're losing the capacity to be able to handle it.

"A very quick response is really important. And, from my experience over many years of working with companies, the problem areas are mostly involved where high pressure wasn't expected, and so they weren't monitoring closely and weren't thinking, 'if we have an influx, this is what we've got to do'.

"And you don't have a lot of time sometimes to react to an influx. You know you're in a high pressure area, and you can anticipate it; even if you're drilling exactly to the book, if you drill and you respond very quickly, nearly every single incident I've ever been involved with or know about has been handled professionally and without incident."

With oil and gas companies moving into increasingly extreme and technologically demanding areas, Swarbrick said operators need to maintain their high standards.

"My personal opinion is that the oil industry does a phenomenally good job in preparing for and drilling, in the main, in extremely hostile conditions.

"If we go back to the 1960s, we were looking at drilling in the North Sea for the first time. At that time that environment was considered the frontier … The frontier then was 600 ft of water, or 200 m; that was the shelf edge, and nobody drilled beyond that except for science. Now we're drilling in 5,000 to 10,000 ft, and most of those wells, in fact almost all of those wells, are drilled safely and responsibly and without incident.

"And it's to satisfy a global demand for crude oil. So, until we've weaned the world's population away from oil, we are going to have to supply an energy mix that includes crude oil from these high pressure regions.

"We have to go and find oil where it exists, and I think the oil industry is prepared to accept what is needed in terms of regulation and new technology, and works very hard to get that technology right.

"And I don't think we should allow the press and popular opinion to think that the industry is failing because there has been one or two incidents. The industry, in the main, is doing a phenomenally good job. The rare incidents highlight the risks and remind us all of the high standards of safety and respect for the environment needed, especially in the future when more of our global oil will be sourced from hostile and other high pressure settings." ■