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Emerging Issues

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The Deepwater Horizon Accident

Written by James Shallenberger

The April 20th, 2010 accident involving Transocean's Deepwater Horizon drilling vessel and BP's Macondo well (Mississippi Canyon Block 252, MC252) claimed 11 lives and continues to escalate into a monumental environmental and economic catastrophe. The cause of the blown oil well appears to be a flawed well plan that specified an insufficient cement volume placed in the annulus between the well's production and protective casing components. Ineffective cementing enabled natural gas to migrate from the petroleum reservoir into the production pipe, thereby triggering the loss of well control.

Oil Well "Blow Out" and How the Well Failed

Production casing is analogous to a drinking straw inserted into a glass of liquid. Except, unlike a glass of juice, the oil reservoir is under tremendous fluid pressure owing to miles of overlying geologic materials and seawater. As the drilling stem is advanced toward the petroleum reservoir, protective casing is inserted into the borehole and cemented into place in sequential stages. Ultimately, the production tubing lies at the center of a progressively tapering "telescope" of steel casing pieces. The integrity of the well's production tubing depends on a series of cement seals that are pumped into the intervening space ("annulus") between the borehole and the outer surface of adjacent casing as well as between the outer and inner surfaces of the various nested casings. Figure 1 shows a well casing schematic with details for the cement seals used on the MC252 well.

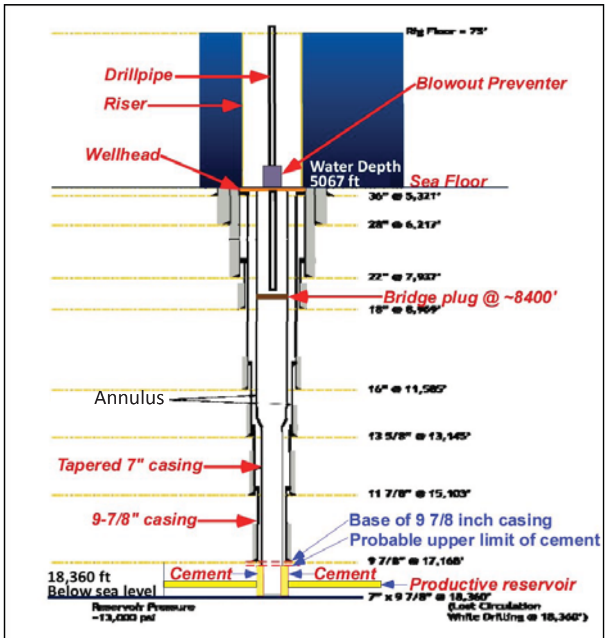

Figure 2. Mississippi Canyon Block 252 well schematic diagram (modified from www.tudorpickering.com/pdfs/tph.well.slides.pdf).

FIGURE 1. Schematic diagram of casing details in the Macondo MC252 well

Source: Berman, A. What caused the Deepwater Horizon disaster? 5/21/2010; The Oil Drum www.theoildrum.com Modified to label annulus.

Upon reaching the reservoir depth, the deepest protective casing segment is supposed to be sealed tight against the ceiling of the reservoir's geologic formation and the outer surface of the production tubing, in turn, is sealed tight within the production casing. The efficient and safe recovery of oil and gas demands a continuous tight seal from the reservoir depth to the surface.

An offshore oil well is installed by a specialized drilling rig that operates from a fixed platform or a floating vessel like the Deepwater Horizon, as was the case for BP's MC252 well. Once the well is drilled and cased, the drilling rig is swapped-out for a production rig that completes the well installation process and begins recovering oil. Upon entering its production phase, oil may enter a temporary at-sea holding vessel and be shuttled on-shore or be piped directly along the sea floor to an on-shore refinery.

Drilling and completing an oil well is a complicated business. Drilling and completing a deep oil well is enormously complicated. Drilling and completing a deep oil well in deep water is exponentially complicated. Completing a deep oil well in deep water with compromised tubing is fantastically dangerous.

The blow-out of the MC252 well occurred near the end of the months-long well installation phase. As the Deepwater Horizon crew prepared to disengage from the well to make way for a production rig, they inserted a series of three staggered cement plugs inside the well riser to control fluid pressure and temporarily seal the well to allow for safe transfer of the well to the production rig's crew. The Transocean crew reportedly also requested to leave drilling fluid in the riser column between the plugs to further bolster control of the well pressure, but BP reportedly overrode Transocean's request and specified seawater in lieu of heavier drilling fluid in the space between at least two of the plugs Unfortunately, a gasket called an annular that is part of a blow-out preventer (BOP) device used to secure pressure within the well and seal it, if necessary, reportedly was damaged weeks earlier (source: CBS News 60 Minutes interview of Deepwater Horizon survivor Mike Williams 5/16/2010).

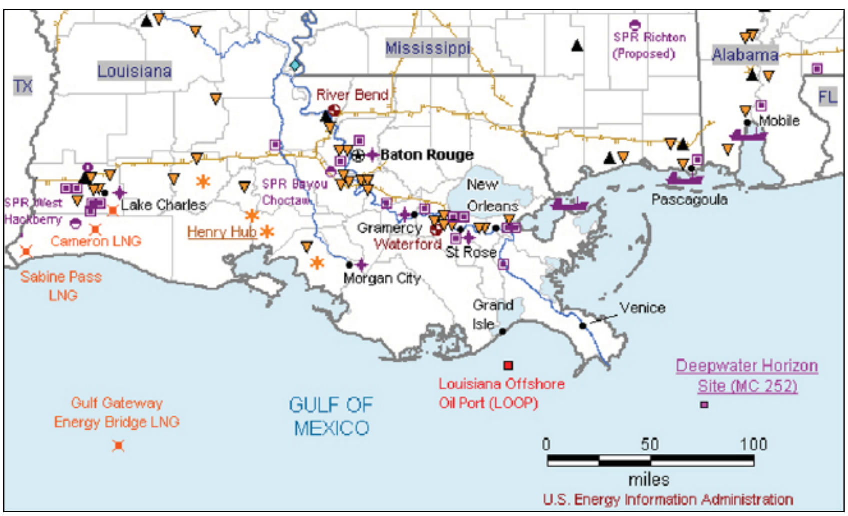

FIGURE 2. Deepwater Horizon site location map

Source: United States Energy Information Administration www.eia.doe.gov

Since the accident, much attention has been given to BOPs. A BOP is positioned on top of the wellhead at the sea floor (refer to Figure 1) and serves to provide pressure control to operators during the drilling phase. A BOP is designed to rapidly shut off the flow of oil or natural gas in a well by compressing, crushing, or shearing the pipe via a hydraulic system in the event of a sudden, unexpected release of pressure within the well. At the time of the Deepwater Horizon explosion, the drilling process was complete - meaning the MC252 well had been sealed with casing and cement - and shortly thereafter, BOPs would have been removed and responsibility for pressure control from the reservoir would rest with the well's cementing and casing components.

As the Deepwater Horizon crew conducted pressure testing on the MC252 well, the damaged gasket provided flawed results about the cement seals (source: 60 Minutes interview). Subsequent events and Transocean's well logs suggest that the space between the production and protective casing in the MC252 well was compromised and an influx of formation fluids (natural gas and oil) penetrated the production tubing, probably where the base of the production casing entered the ceiling of the petroleum reservoir.

Transocean's logs of April 20th, 2010 showed that the MC252 well failed a negative pressure test (i.e., influx of fluid) at around 5:00 PM that day. The mud circulating logs reflected increasing pressure within the well at 8:00 PM and again after 9:00 PM (source: Berman, A. What caused the Deepwater Horizon disaster? 5/21/2010; The Oil Drum www.theoildrum.com). The blow-out occurred just past 9:45 PM that night.

Repairing or Closing the Well

The MC 252 well was installed 50 miles from the Louisiana coast in 5,076 feet of water. The well was drilled to a depth 13,293 feet below the sea floor. The blown MC 252 well cannot be repaired. Since the accident, BP has attempted to stem the flow of oil and natural gas from the well by several means including activation of the BOP; capturing and diverting the flow of oil using various "box" vessels and tubing inserts; creating a temporary plug in the well by inserting a mixture of "junk" and drilling fluids; and, cutting and capping the damaged riser. Some of the attempts to divert leaking fluids have succeeded and partially reduced the uncontrolled loss of oil. In the meantime, oil continues to flow from the damaged well – on May 27th, the United States Geological Survey (USGS) estimated the rate of oil release from MC252 at between 12,000 and 19,000 barrels per day (bpd) or approximately 500,000 to 800,000 gallons per day (gpd).

Additionally, on May 3rd, work on the first of several planned relief wells was begun. A relief well represents the ultimate solution to close the blown MC252 well. The relief well concept requires drilling a new well that will intersect the damaged well deep beneath the sea floor. The relief well will be used to tap the blown well. Once tapped, the relief well will serve as a conduit to introduce fluids that will permanently seal the MC252 well. BP estimates that to install a relief well and seal MC252 may take 60 to 120 days.

Minimizing the Impacts of the Spill

A Multi-angle Imaging SpectroRadiometer (MISR) instrument deployed aboard NASA's Terra spacecraft created images of the Gulf oil plume on May 17th, 2010. Figure 3 depicts a false-color image created by combining data from the red band with the blue and green bands of different on-board cameras. The result causes the oil spill to stand out dramatically in shades of cyan, while other features like clouds and land appear close to their natural color. The Mississippi River Delta is visible in the upper left portion of the image.

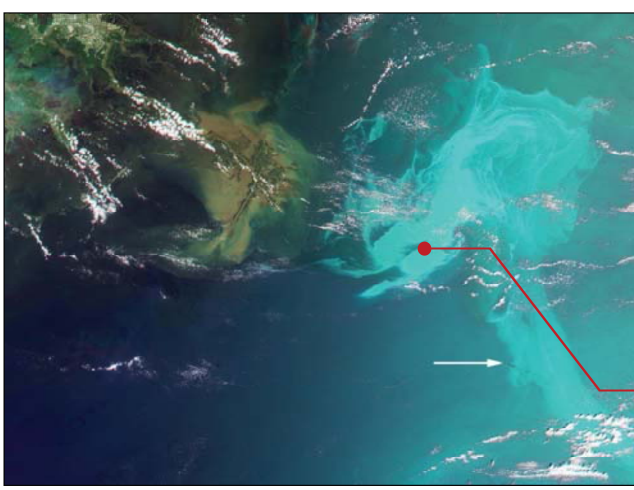

FIGURE 3. NASA's Multi-angle Imaging SpectroRadiometer portrays the extent of oil in the Gulf of Mexico on May 17, 2010 originating from the Deepwater Horizon accident site. The white arrow points to a plume of smoke, most likely from a controlled burn of oil collected on the surface.

Source: National Aeronautics and Space Administration
http://www.nasa.gov/topics/earth/features/oil20100520-b.html

BP's Mississippi Canyon Block 252 "Macondo" well

Oil recovery and dispersal operations have been underway since the on-set of the Macondo well incident; however, as of early June, oil residue was reportedly detected along 125 miles of Gulf Coast states belonging to Louisiana, Mississippi, and Alabama. As of June 3rd, one leading edge of floating oil residue was a few miles from Florida's Panhandle beaches. Moreover, oil residue was reported on several current streams that could convey it well beyond the Gulf States region. The spill response has included the use of oil dispersants applied both above and below the sea surface, floating recovery skimmers, oil absorbent booms, and controlled burns of floating oil masses at sea.

FIGURE 4. A freighter traverses floating oil that originated from the Deepwater Horizon accident in the Gulf Of Mexico.

Source: Jae C. Hong - AP

FIGURE 5. Images of oil spill cleanup activities in the aftermath of the Deepwater Horizon accident. Upper left – oil absorbent booms placed around coastal island (Reuters); Upper right – dispersant applied from aircraft (Reuters); Lower left – controlled burn of floating oil (Ann Marie Gordon, USCG – AP); Lower right – response vessels at sea (Reuters).

Anticipated Environmental Impacts of the Spill

As an oil spill unfolds, wildlife mortality rates generally peak early, then recede. Early wildlife mortality occurs mostly due to the physical effects of external oiling and smothering; sea birds and shore birds are especially vulnerable to the effects of being oiled.

Crude (raw) oil is a mixture of mostly hydrocarbon molecules, various nitrogen and sulfur-bearing compounds, as well as a multitude of “impurities” (mostly trace metals). Crude is frequently described using terms such as light or heavy and sweet or sour. The adjectives light/heavy refer to the relative proportion of impurities; whereas, sweet/sour describes crude oil that is low/high in sulfur compounds. In general, Gulf of Mexico crude is characterized as light and sweet.

Hydrocarbon molecules in crude oil range from aliphatic (straight chain) compounds to more complex aromatic (containing a benzene ring) and polynuclear aromatic (containing two or more benzene rings) compounds as well as heavier asphaltenes. Hydrocarbons also may occur in the complete range of physical states (i.e., gas, liquid, solid). In light and medium crude oils, short chain aliphatic and aromatic compounds dominate. Hydrocarbons in general exhibit low polarity (electrical charge) and therefore have low water solubility, but high fat solubility.

As soon as a petroleum mixture enters an environmental realm (water, soil, air), weathering processes begin to adjust the composition of the mixture. The very lightest constituents evaporate; other substances dissolve in water; and, as the mixture encounters solids, compounds adsorb or otherwise bind to surfaces. As weathering processes occur, the proportion of the mixture changes to become progressively more enriched by heavier molecules.

The long-term environmental toxicology of oil spills emphasizes the fraction of hydrocarbon molecules known as polynuclear aromatic hydrocarbon (PAH) compounds, of which there are many individuals. PAH are further commonly subdivided according to chemical structure traits or by molecular weight (or carbon number, CN, literally the number of carbon atoms per molecule). In general, low molecular weight PAH exhibit higher volatility and water solubility than high molecular weight PAH compounds. As a consequence, lighter PAH compounds tend to be less persistent than their heavy PAH counterparts. In general, environmental persistence can be thought of as a proxy for ecological toxicity. Comparatively non-persistent substances tend to exert acutely toxic effects, but less likelihood of chronic effects – their high volatility and aqueous solubility rates make exposure to high concentrations possible in the near-term; however, such traits also lend well to biological elimination. Whereas, greater environmental persistence means that the substance is made available more gradually (read: for longer duration) and due to a strong affinity for fats, heavy PAH may accumulate in living organisms and induce toxic effects through chronic exposure since theses substance are more resistant to the protective responses of organisms.

Long after oiling effects have worn off, toxic effects from the spill may persist.

Source: NationalGeographic.com

In the near-term aftermath of the MC252 well failure, BP applied oil dispersants in efforts to physically break apart large masses of oil, possibly avert some of the physical effects of oiling, as well as exploit the weathering processes that naturally degrade oil components. Weathering reduces the overall toxicity of petroleum mixtures, especially the potential for toxic effects from acute exposure. However, by accelerating the break-up of oil masses into smaller droplets (high surface area to volume ratio), because high molecular weight PAH exhibit low aqueous solubility, they tend toward strong affinity for lipids and therefore high CN PAH may accumulate in living organisms and induce toxic effects through chronic exposure.

Chronic exposure to heavy PAH compounds tends to impair cellular viability, cause DNA damage, reduce immune system function, and induce narcotic effects. The long-term toxicological exposure effects of an oil spill depend largely on the environmental setting and the biotic community that inhabits it. Along tidal shorelines, oil residues tend to persist longer in higher versus lower tidal elevation ranges owing to the more frequent flushing that occurs in the lower elevation range. Where the shoreline substrate allows oil residues to infiltrate and accumulate in interstices (i.e., spaces between adjacent sand, gravel, rock or within the framework of shell beds), heavy PAH compounds may persist for decades. In such situations, certain organisms or life stages may be vulnerable to chronic exposure effects of oil residue.

For example, some fish species deposit eggs and the hatched larvae tend to “incubate” in benthic crevices. Although the aqueous solubility for heavy PAH compounds is generally low, some dissolution does occur and aqueous-phase PAH may concentrate in the “pore water” of these settings. Moreover, the eggs and larvae are relatively enriched in fatty tissue types that high CN PAH tend to accumulate within. Similarly, organisms that forage near-shore settings extensively such as various long-billed shorebirds that probe the substrate may be vulnerable to chronic effects of oil residue for prolonged periods following a spill.

About the Author

Mr. Shallenberger has more than 15 years professional experience as a consulting ecologist and geologist in a career that has emphasized the design, management and execution of water and wetland resource sampling and analysis projects. He has planned, coordinated, implemented, and/or evaluated complex and multi-faceted scientific investigations pertaining to: contamination of soil, groundwater, and surface water resources; point and non-point source pollutant characterization of waterways; and Ecological Risk Assessment (ERA) planning, evaluation, and interpretation of stressor impacts to sensitive organisms/communities, including ecological and biological investigations and analyses to characterize community assemblages, identify suitable habitat, perform ecological functional assessments, and inventory natural resources in terrestrial, wetland, and aquatic settings.

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