COMBINING MODELING WITH RESPONSE IN POTENTIAL DEEP WELL BLOWOUT: LESSONS LEARNED FROM THUNDER HORSE[1]

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ABSTRACT

In May of 2003 a drilling riser break at a BP development well in 6015 feet (1875 m) of water in the Gulf of Mexico initiated a dialog between BP responders and NOAA/HAZMAT modelers about the potential consequences of a deep well blowout.

Human health and safety issues were the key concern for BP responders, particularly those planning potential on water operations. Where might the gas surface? Would the natural gas (propane and methane) at the water's surface pose an explosion or asphyxiation hazard? Was there a potential for the gas bubbles to sink any of the response vessels? These discussions did not have as cut-and-dry answers as either BP or NOAA would have preferred.

During the planning for BP's attempt to bring the well back into operation, the General NOAA Oil Modeling Environment (GNOME) with the Clarkson Deep Oil and Gas model (CDOG, Zheng et al 2003, Chen and Yapa 2003 and Yapa and Cheng 2004) were run. The data required for modeling a deep spill is more extensive then for a surface oil trajectory and was the subject of much discussion between BP responders and NOAA/HAZMAT. As a result, NOAA/HAZMAT created a data summary request sheet (Appendix 1) to guide the BP responders in what data was needed, and provided a point of discussion for implications of missing data.

INTRODUCTION

On May 21, 2003, a drilling riser break occurred in a development well 60 miles south of Southwest Pass, Mississippi River Delta (28° 11' 25.480" N, 088° 29' 42.918"W) in 6015 feet (1875 m) of water. Over the next few weeks, The NOAA Office of Response and Restoration (ORR) and BP Exploration and Production worked together to answer questions that arose from the initial release of drilling mud and the subsequent repair process. Since this was a deep well, the potential for a deep well blowout was on everyone's mind as contingency plans were put in place. The goal of this paper is to document the questions raised and lessons learned from the interactions between the modelers and potential responders for future consideration.

The topics included in this paper are:

- Potential environmental hazard from initial loss of drilling mud.
- Supporting Planning Process for Relief Well Drilling. Increased data exchange requirements for deep well blowout contingency planning. Data availability for modeling needs;
- Human health and safety issues of deep well blowout: surface gas hazards to humans, and potential of sinking a vessel in released gas bubbles.

THE SCENARIO

The early morning routine on the 103,000 ton drillship Discoverer Enterprise was shattered by a tremendous jolt from the riser tensioner system recoiling. Everyone onboard knew instantly that something had gone terribly wrong. Crewmen quickly launched a remotely operated vehicle and found that the drilling riser had parted and that only half of the 6,000 feet of riser was still attached to the ship.

The target total depth of over 24,000 ft on the Mississippi Canyon 822 No. 6 well had been reached. With the primary pay zone exposed, crewmen were in the process of "pulling out" of the hole. When the drilling riser snapped, the Blow Out Preventer's (BOP's) "dead-man" controls functioned as planned: shearing the drill string and stopping the well from flowing. No one was hurt, and the well was secure, but the initial scene was daunting. Two thousand feet of riser lay scattered on the seafloor, another 3,000 feet of pipe was still attached to the drillship, and another 1,000 feet of riser was simply dangling—ready to fall on the BOPs. The top connector of the BOP was damaged, with one joint leaning against the BOP, dangerously close to the control lines (see photos below). Loss of well containment would result in more oil spilled in a week than occurred during the whole of the T/V Exxon's Valdez oil spill.

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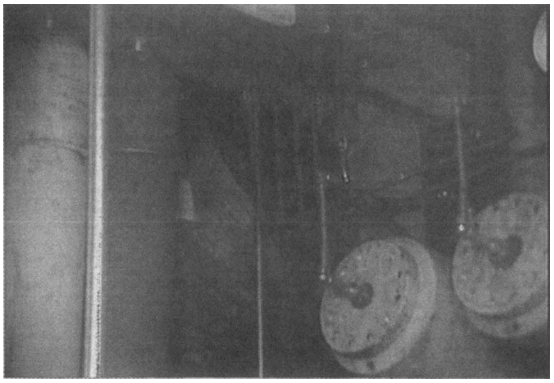
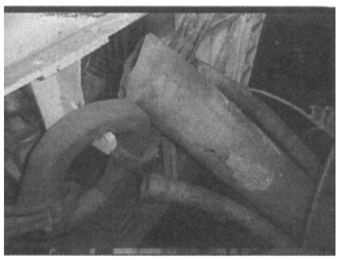
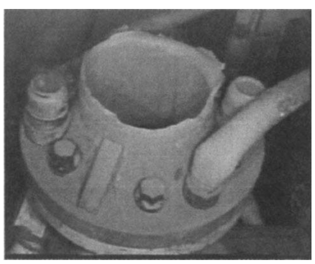


RISER JOINT NO. 1 LAYING AGAINST BOPS



CLOSE UP OF RISER JOINT NO. 1



TOP OF LOWER MARINE RISER PACKAGE (LMRP) WHERE JOINT NO. 1 HAD BEEN CONNECTED

DRILLING MUD

Approximately 2450 bbls of synthetic based drilling mud were reported lost during the riser break. The NOAA SSC, Charlie Henry, relayed to NOAA the question of whether or not the drilling mud was potentially an environmental problem in such deep water far from shore. The HAZMAT science team discussed the issue and determined that any oil lost from the drilling mud solution was most likely a local effect. If there were any deep sea organisms living off the local methyl hydrate, there is a potential for the deep sea drilling mud to smother them, depending upon how the release occurred. Fortunately, the area had been surveyed for chemosynthetic organisms prior to drilling and none were found in the vicinity.

SYNTHETIC BASED MUD FALLING FROM PARTED RISER

SUPPORTING PLANNING PROCESS FOR POTENTIAL DEEP WELL BLOWOUT AND RELIEF WELL DRILLING

Data Exchange and Availability—What the HAZMAT Response is going to Ask For During a Response.

Hazmat was asked to run the Clarkson Deepwater Oil and Gas (CDOG) Model (Zheng et al 2003) to aid planning for the potential of a deep well blowout and the need to drill a relief well, in order to predict where oil would reach the surface. In order to make such a prediction, more information regarding the spill scenario and local oceanography are needed than during a normal spill. BP provided information on the gas and oil properties, currents measured over the last two days, and a data report on historical currents measured in the area (Evans-Hamilton). Climatological temperature and salinity profile data (Levitus 1982) was used, as no measurements were available. In particular, BP responders were interested in where oil would surface if a blowout happened in the near future, and where gas might surface and threaten responders over the six week course of drilling a relief well.

See Appendix A for Deep Well Blowout Data Preparation Sheet for responders (updated from our original draft used in this case). This sheet is designed to guide responders in collecting the information that HAZMAT needs in order to model a Deep Well Blowout. Unfortunately, some of the information that is critical to modeling the gas oil plume is most likely unknown. HAZMAT used the CDOG defaults for the unknown initial droplet size and gas bubble size distributions. There was also difficulty in getting specific information that we needed vs. the information that was available from the BP chemists. For example, HAZMAT was not able to easily calculate gas molecular weight or potential flammability from the gross constituent list faxed by the BP chemists.

CDOG predicted that oil would initially surface within 4 hours within a few miles northwest of the spill site based on the most recent current observations. CDOG also predicted that the oil would surface over a 20 mile area that extended to the northwest of the spill site during the next 48 hours. See Appendix B for the trajectory information sent to BP including a picture of the area where oil would most likely reach the surface over time.

The surface location for the potential relief well was east-southeast, approximately 6500' east and 3000' south, of the source. HAZMAT ran two cases to bound the question of where the gas could surface. The first case was very simple—25.4cm bubbles of methane released at the pipe orifice with no currents. These bubbles rise directly over the site. The next case was an estimate of how far the bubbles could travel. HAZMAT to create a maximum possible current profile in order to estimate the farthest distance that bubbles could travel, but this type of information was different than the velocity information in the Evans-Hamilton report. For example, in the report, maximum currents were reported as probabilities of currents exceeding 75 cm/s, whereas reporting the actual maximum velocities would have been more helpful in this scenario. Very small bubbles, 6 mm in diameter, were released in the maximum probable currents. These bubbles surfaced a maximum of 33 nm from the release site on the sea floor. During the CDOG simulation, hydrate formation was allowed during oil related simulations, and not allowed in gas related simulations, in order to be conservative in surface gas estimates.

CONCLUSIONS FROM TRAJECTORY MODELING

1. If the potential relief well site(s) can be determined before the initial current observational data reports are complete, the current meter data could be analyzed to aid in relief well planning for oil and gas issues. For example, a current profile climatology or current profile time series for CDOG could be developed

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HUMAN HEALTH AND SAFETY QUESTIONS

Surface Gas Hazards—Inhalation and Flammability

HAZMAT expected that if the gas reached the surface of the water over the relief valve, it will be distributed over a significant area, and the zone where the gas was in the flammability range will be defined by a surface boundary layer. The boundary layer can be thought of as a blanket of air over the source area where the time-averaged concentration of hydrocarbon is above the flammability range, roughly 2% to 5%. This boundary layer would be quite thin at the upwind edge of the gas source area and become deeper as one moves toward the downwind edge. If ignition sources are above the boundary layer, the likelihood of ignition is small. If the ignition source is significantly far away from the gas source area, the likelihood of ignition is also small, and the aerial extent of the gas source does not really matter. HAZMAT does not routinely compute boundary layer properties since most of our modeling is aimed at predicting hazard zones removed from the source location.

Without well validated models of gas movement through the water column, historical current measurements, or good knowledge of the gas bubbles exiting the well, HAZMAT decided to try to bound the problem with some simple conservative scenarios. Since analyses received from BP indicate that the gas would be mostly methane, one scenario was run with pure methane gas. Propane was selected for a second scenario because it has a lower Lower Explosive Limit (LEL) of 2.2%, whereas the LEL of methane is 5%. We also considered the occupational Threshold Limit Value (TLV) of propane, which could be of concern to the workers aboard the relief well.

No TLV was given for methane because it is a simple asphyxiant—the methane itself is not toxic. So, at the LEL of methane, a person could still breath because more of the atmosphere would have to be replaced by methane to cause a breathing problem. Hence, the LEL is the most conservative guideline for human health and safety.

Using the ALOHA air dispersion model, HAZMAT assumed that the most conservative conditions for release would be to (1) mathematically move the 25.4cm orifice at the seabed directly to the sea surface, (2) not allowing the gas to spread out horizontally while rising to the surface through the water column, and (3) not allowing any loss of gas due to dissolution or hydrate formation. A source strength of 85.5 million std cu ft/day was provided by BP. We chose the most conservative atmospheric stability class to minimize the vertical mixing of the gas in the atmosphere and so maximize the distance traveled by the plume.

ALOHA Results

For the **TLV level of propane** (800 ppm)

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 800 ppm
Max Threat Zone for LOC: 1.7 miles

For the **2.2% LEL for propane**
Total Amount Released: 402,131 pounds
FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 22,000 ppm
Max Threat Zone for LOC: 450 yards

For **5% LEL for methane**
Total Amount Released: 144,420 pounds
FOOTPRINT INFORMATION:
Dispersion Module: Gaussian
User-specified LOC: 50,000 ppm
Max Threat Zone for LOC: 381 yards

Conclusions for Human Heath and Safety For Potential Gas Surfacing

1. Air monitoring would be necessary under all conditions to provide real-time information on human health and safety issues.
2. There is a possibility of surface flammability from the gas surfacing.
3. The potential for the rising gas to contain hydrogen sulfide is important for the operators to be aware of.

Potential for Gas Bubble to Sink a Response Vessel

A literature and Internet search was conducted for cases histories or anecdotal evidence of vessels sinking due to buoyancy loss from rising bubbles. Only one suspected case was found: a sunken vessel located in the Witch Ground area of the North Sea (Marchant 2001). The bottom in this area of the North Sea is noted as "pockmarked" from gas releases, and active gas releases are present. By the position of the vessel on the bottom, it is thought to have sunk straight down by being swamped, rather than sinking stern or bow first.

Laboratory experiments on small scale indicate that in a rising plume of small bubbles (smaller than the vessel), the vessel is more likely to be pushed aside rather than sink provided the fluid is confined (i.e. the fluid can move away from the bubble source area (May and Monaghan 2003). This is because the rising bubbles entrain water to move upward with them. With a continuous bubble stream, the rising water is forced to the sides once reaching the surface.

In the case of large bubbles rising, if the bubble is larger than the vessel, the vessel's position relative to the bubble is key (May and Monaghan 2003). If the vessel is directly on top of the bubble, the vessel will drop down into the water when the bubble bursts, but not necessarily sink. If the vessel is not located on the top of the bubble, it will slide down the side resulting in the leading portion of the vessel being forced underwater. This is likely to make the vessel sink. Frictional constraints suggest that bubbles the same size or larger than open water vessels are not likely, as large bubble tend to shear and break into smaller bubbles upon rising.

Conclusions for Gas Bubbles Sinking a Vessel

1. The possibility of a ship sinking due to buoyancy loss from bubbles is a large concern for responders, but only theoretical and anecdotal evidence exists.

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Appendix A

NOAA/HAZMAT Deepwater Spill
Incident Data Preparation Sheet
Version September 12, 2003

Incident Name:____

Spill Location: ____________________, _________________________

Spill Depth:_______________[ft or m] conversion_______________[m]

CDOG Spill Release Parameters

(Choose 2) Oil discharge rate: ________ [m3/s] [Bbls/day]

Gas discharge rate: ________ [m3/s] [MSCF/day] [2]

Gas to Oil ratio __________ [by volume]

Diameter of orifice: _______________[in or cm] conversion _______________[m]

Initial bubble radius: _______________[mm] or *unknown* (choose 1)

Temperature of Discharge Mixture: ____________[deg C] [deg F] (Circle 1)

Conversion to _______________[deg C]

Density of Product at Average Water Temp: _______________[kg/m3] [API]

Oil droplet size distribution: __________ or unknown (choose 1)

Choose 1 gas type: Methane

Natural Gas

Molecular weight: _____________[kg/mol]

Density of hydrate: ___________ [kg/m3]

Does gas contains hydrogen sulfide? Yes No

Hydrodynamics—Check off as data sent to NOAA

_______Ocean Current Data—Observed Profile Available? Yes No

_______Temperature/Salinity Data—Observed Profile Available? Yes No

_______Horizontal Diffusivity:_____________[cm2/s2]

_______Vertical Diffusivity:_______________[cm2/s2]

2 MSCF = thousand standard cubic feet

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APPENDIX B

Date: 1830 CDT May 22, 2003
To: NOAA SSC Charlie Henry

FROM: NOAA/Hazardous Materials Response Division
Modeling and Simulation Studies
Seattle, WA 98115

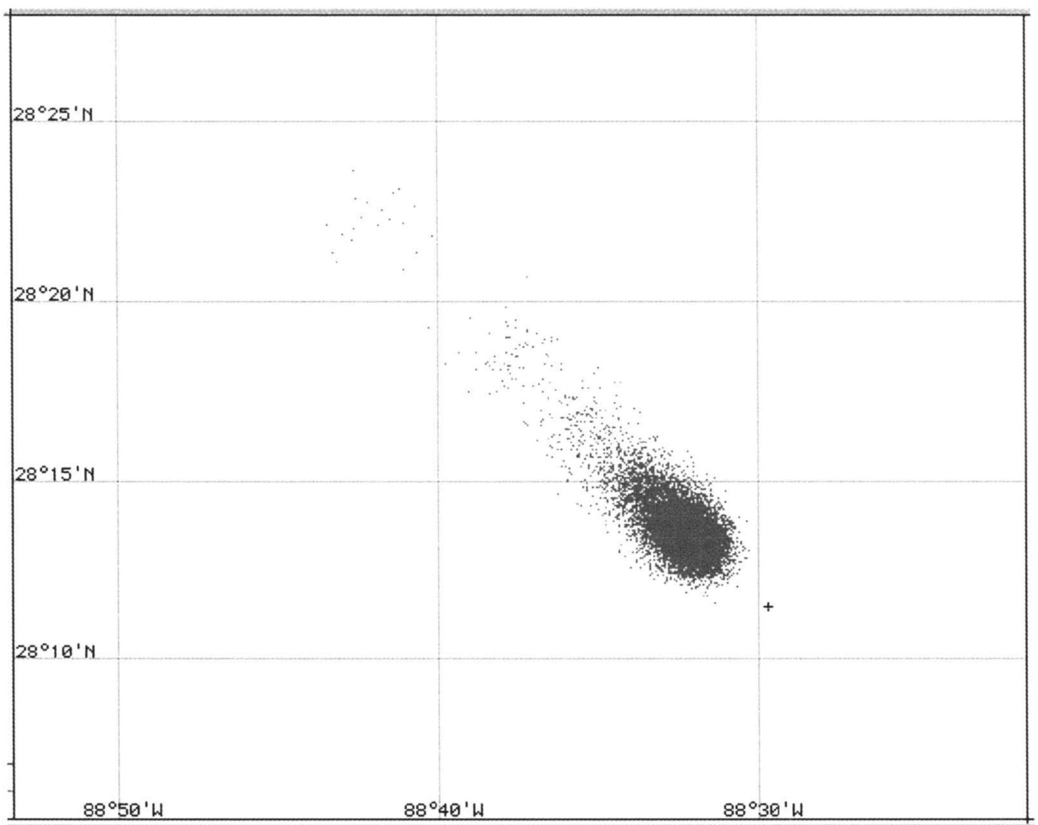
SUBJECT: Potential Deep spill release, Gulf of Mexico

FOR ADDITIONAL INFORMATION, PLEASE CONTACT CJ Beegle-Krause
MODELING AND SIMULATION STUDIES, NOAA, SEATTLE, WA 98115.
PHONE (206) 526-4911.

We have looked at the trajectory implications of a potential deep well spill in the northern Gulf of Mexico. These notes are based on the following information:

A well located at 28° 11' 25.480" N, 088° 29' 42.918° W at a depth of 3000 feet (1875 m). The GOR is 900 with a release rate of 100,000 bbls/day from a 10" diameter orifice. The oil has an API of 33. Current profiles were provided; temperature and salinity profiles are from climatology.

If any of this initial information is incorrect, please let us know ASAP as it would affect any trajectory implications.
1) TRAJECTORY



The picture above shows the most likely footprint where oil would surface. We estimate that oil would begin to surface within 4 hours after first release.

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