Macondo Technical Note

Title:	Shut-in Pressures: Range and Likelihood
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Question Addressed in this Technical Note:
As BP is currently evaluating kill options for the Macondo well, this technical report addresses the following questions:

- What is the likely range of shut-in pressures at the well head (SIWHP)?
- What probability of occurrence can be assigned to each of the calculation methods.
- Is it likely to change over time?

This note expands upon earlier work documented in a draft technical note dated 17-May, as well as yesterday's draft of this note. We were requested by Kate Baker to reconsider the questions in light of continued efforts:

1. Having had a chance to think on this are you still satisfied with the probability you described on Wednesday and with the work done overnight?
2. What would be your view of probabilities if you assume that the GOR is 3000 SCF/stb instead of 7500 SCF/stb?
3. Following completion of 1 and 2 create a set of bins and describe the probability of each such that they sum to 100%: e.g. oil 8100-8500; gas 10200-10700; M57 only 11300; GOR=7500 with 9600 psia; and GOR 3000.

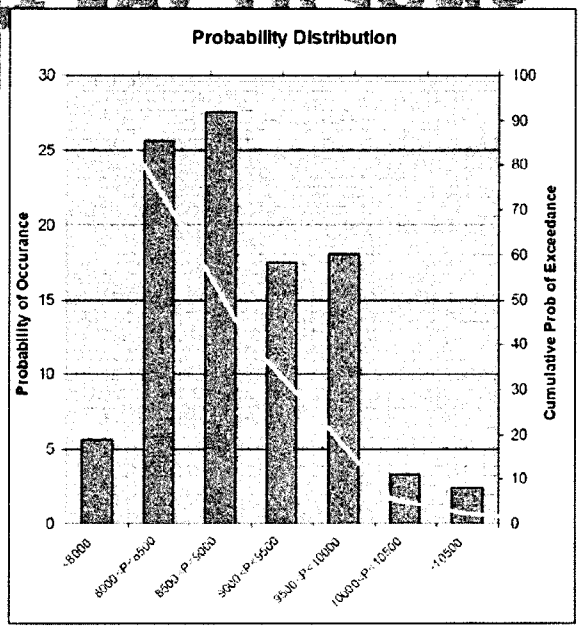
Having considered these additional questions, the probability distribution presented in this note is updated.

Overnight we were able to create a "GAP" model which modelled crossflow and WHP. This model was interrogated and the results were influential. The Olga simulation results became available and some additional Olga runs were performed within the team.

A VIP simulation model was started to consider the crossflow from a detailed reservoir perspective. However, this model was not completed at 2pm on 20-May, and these findings do not incorporate those results.

Key Conclusions

1. The SIWHP is expected to be between ~7,500 psia and 11,350 psia.
   - This range considers the impact of shallower high pressure gas zones, which are found at depths between 17,467 – 17,806 ftMD-RKB.
     - There was consensus that these gas zones were likely to be open, but the contribution and depletion of these zones was an area of uncertainty.
     - The shallower gas zones at 12,030 – 13,320 ftMD-RKB are behind the 13⅝ inch liner and are not likely to increase the stated range of SIWHP.
   - The lower pressures occur when the gas zones are not areally extensive. This is the geologists' interpretation. Although initially at a high pressure, they deplete quickly, establishing crossflow from the oil zones when the well is shut-in which lowers the wellhead pressure.
2. The team was requested to estimate the likelihood of SIWHP exceeding a number of values. The following is a chart which gives the estimates both as a cumulative probability function and as discrete events.



These results are also provided tabularly:

Description	Pressure Range psia at wellhead	Probability to Exceed	Discrete Probability
Low Estimates	7500	100%	0%
Oil + Depleted Gas Sands	<8000	94%	6%
Oil (GOR ~3000 SCF/stb)	8000 < P < 8500	69%	26%
Oil + Limited Gas	8500 < P < 9000	41%	28%
Oil (GOR ~7,500 SCF/stb)	9000 < P < 9500	24%	18%
Oil + Gas	9500 < P < 10000	6%	18%
Oil + extensive Gas sands	10000 < P < 10500	2%	3%
High Pressure Gas column	10500 < P		2%
Highest estimates	11,350	0%	0%

3. The Enterprise has reported considerable variation in the gas-oil ratio of the recovered oil. These GORs range from an initial 2,850 SCF/stb, consistent with the oil's PVT data, to almost 7,500 SCF/stb. The GORs show an increasing trend which can be correlated with increasing choke orifice size. A tidal variation has also been observed.

   - The 7,500 SCF/stb value is consistent with a calculated SIWHP of ~9,500 psia.
   - The 3,000 SCF/stb value is consistent the team's previous calculations with oil which result in a SIWHP of ~8,500 psia.
   - The lower GOR is more consistent with areally-limited gas sands which would not provide the inflow which would result in the higher calculated SIWHP.
   - Samples collected at the surface are not representative of the fluid flowing from the wellhead except by coincidence, because of the nature of the collection system.

4. The Olga simulations indicate that the well will be filled with both vapor and liquid phases.

   - At a low GOR of 3000 SCF/stb, the oil will fill most of the well, but approximately 500 ft of gas will be at the top of the well.
   - At a higher GOR of 7,500 SCF/stb, the gas column expands to fill the top 4,500 ft. of the well.
   - The segregation of the oil and gas occurs within the 24 hours following shut-in.

Attachments

1. Pressure Ranges and Calculation Methods
2. Method for Establishing probabilities

3. Table of Formation Properties
4. Thermal Gradient

Model Results of Shut-In Pressure for Macondo Well

Modelled Sand(s)	SI WHP	Tool	Correlation	Gradient
M56E Oil, GOR ~3000 SCF/stb	8,164	Pipesim	EoS Tables	Geothermal
M56F Oil, GOR ~3000 SCF/stb	8,169	Pipesim	EoS Tables	Geothermal
M56D Oil, GOR ~3000 SCF/stb	8,181	Pipesim	EoS Tables	Geothermal
M56e,d,f; GOR ~3000 SCF/stb	8,351	Prosper	Al-Marhoun	Geothermal
M56A Oil, GOR ~3000 SCF/stb	8,481	Pipesim	EoS Tables	Geothermal
Lower Oil Sands + Gas Zone	8,503	Prosper	Al-Marhoun	Geothermal
Lower Oil Sands + Gas Zone	8,605	Prosper	Vasquez-Beggs	Geothermal
M56E Oil	8,232 - 8,860	Excel	Incompressible	none
M56E Gas	10,200	Excel	Hall-Yarborough	linear
M56A (2nd sand @17804) Gas	10,372	Prosper	Al-Marhoun	Geothermal
M56A (as gas-filled)	10,569	Pipesim	EoS Tables	Geothermal
M56A+M57B Gas	10,797	Prosper	Al-Marhoun	Geothermal
M57B Gas	11,184	Prosper	Al-Marhoun	Geothermal
M57B Gas	11,327	Pipesim	EoS Tables	Geothermal
M57B Gas	11,363	Excel	Hall-Yarborough	linear
Oil, GOR = 7500	9,450	Prosper	Al-Marhoun	Geothermal
Oil, GOR = 7500	9,600	Pipesim	EoS Tables	Geothermal
M56F Zone Only	7,959	Olga	EoS Tables	Geothermal
M56E Zone Only	8,238	Olga	EoS Tables	Geothermal
M56D Zone Only	8,213	Olga	EoS Tables	Geothermal
M56A Zone as oil	8,510	Olga	EoS Tables	Geothermal
M56A Zone as gas	9,190	Olga	EoS Tables	Geothermal
M57B Gas	10,013	Olga	EoS Tables	Geothermal
Zone 56DEF assumed 10mbd rate	8,385	GAP	Prosper hydraulics	Geothermal
Zone 56A, 57B + 56DEF unconstrained	7,515	GAP	Prosper hydraulics	Geothermal
Zone 56A, 57B + 56DEF @10mbd	8,415	GAP	Prosper hydraulics	Geothermal
Zone 56DEF; 10mbd; + aquifer	8,515	GAP	Prosper hydraulics	Geothermal
Zone 56A, 57B + 56DEF @5mbd; 10x volume in gas sand	8,615	GAP	Prosper hydraulics	Geothermal

Method Used to Develop Cumulative Probabilities

The cumulative probabilities were determined through a polling process. The petroleum and reservoir engineers were presented the model results, the modelling assumptions, and the other considerations / constraints.

Each engineer was asked to consider a range of values (7500, 8000, 8500, 9000, 9500, 10000, 10500, and 11350 psia) and estimate in their own best judgment the probability that the SIWHP would exceed that value. It was assumed that the end pressures (7500, 11,350 psia) defined the 100% confidence interval.

After each engineer wrote down their values, they were polled in a random order for their estimated probability. These were then averaged to create a cumulative permeability curve for each pressure.

The resulting curve was plotted. The statistics associated with each point (after the 5% shift) are provided in the following table:

Pressure	Mean Probability to Exceed	Min Probability	Max Probability
7500	100%	100%	100%
8,000	94%	85%	100%
8,500	69%	50%	90%
9,000	41%	20%	70%
9,500	24%	10%	50%
10,000	6%	0%	20%
10,500	2%	0%	10%
11,350	0%	0%	0%

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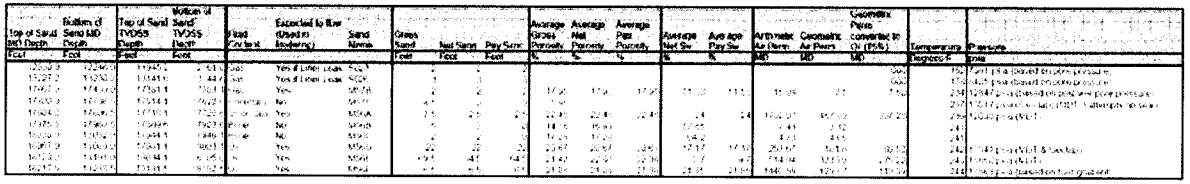
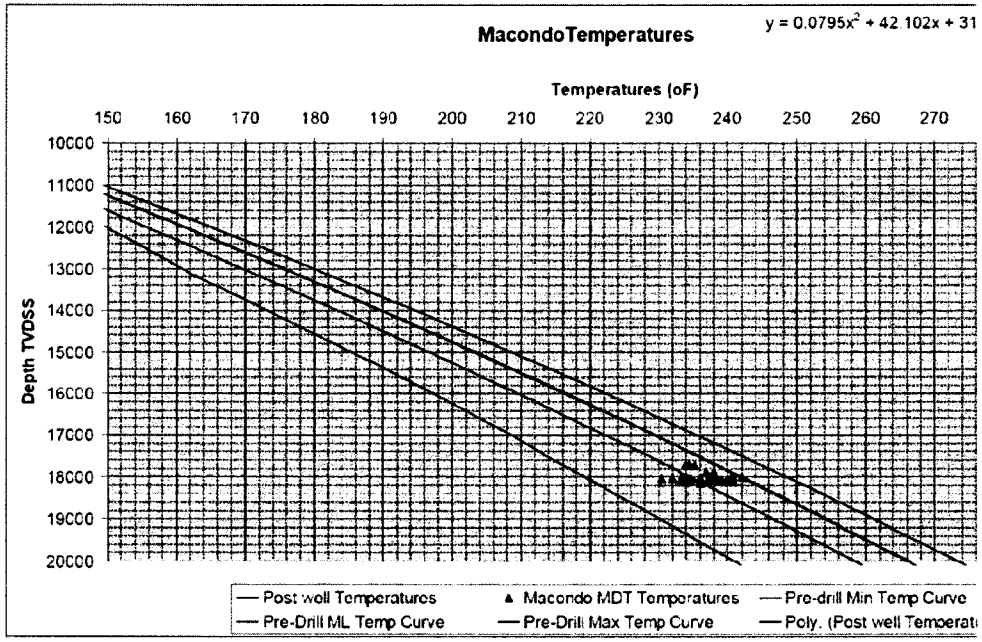
Layer Properties Used for Calculations



Draft for Discussion

Thermal Gradient



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