From: Mason, Mike C
Sent: Sat May 15 00:58:50 2010
To: Turnbull, Jon B
Cc: O'Bryan, Patrick L; Tooms, Paul J; Cecil, Chris; Kercho, Debbie A
Subject: Macondo SIWHP & Build-up Rate Final Report.doc
Importance: Normal
Attachments: Macondo SIWHP & Build-up Rate Final Report.doc

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This is version A of the above referenced report it will be updated as version B after we get SIWHP conclusions from the National Laboratories and additional data from one of the contributors.

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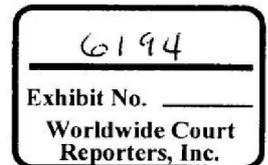
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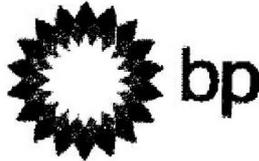
## Technical Note

| | |
|---|---|
| Title: | Macondo SIWHP and Build-up Times |
| Prepared by: | Mike Levitan, Debbie Kercho, Farah Saidi, Simon Bishop, Tony Liao, Thomas von Schroeter, Kelly McAughan, Chris Cecil |
| Reviewed by: | Debbie Kercho and Chris Cecil |
| Approved by: | Mike Mason |
| Date: | May 14, 2010 |
| Revision: | A |

### Question Addressed in this Technical Note

As BP is currently evaluating kill options for the Macondo well, this technical report addresses the following question:

What is the estimated shut in pressure character for the well addressing:

  a) time for Pressure Build Up at normal SIWHP

  b) ultimate shut-in pressure taking into account both the oil bearing and gas bearing sands?

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**Key Conclusions**

1) The SIWHP is expected to be between 8,400 psia and 8,900 psia for the oil sands between depths 18,060' and 18,200' (MD-RKB). This assumes no reservoir depletion.

2) The average SIWHP is 0 – 10 psi higher than those listed above in item 1) when flow from the gas sand is included in the calculation.

3) The maximum SIWHP could be as high as ~10,340 psia for the gas sand at a top depth of 17,802' (MD-RKB) assuming the oil sands do not contribute to flow. This would necessitate a sealing-off of the oil sands not yet observed and therefore is considered highly unlikely. Dry gas and no reservoir depletion were assumed.

4) The time required for oil sands between depths 18,060' and 18,200' (MD) to build-up to a static SIWHP depends on the assumed location of the flow restriction.

   a. for a case in which there is a flow restriction at a shallow location in the well the time to build-up to a nearly-static SIWHP is on the order of 5 minutes.

   b. for a case in which there is a flow restriction located deep in the well the time to build-up to a nearly-static SIWHP is on the order of 30 minutes.

5) When both the gas sand at a top depth of 17,802' (MD) and the oil sands between depths 18,060' and 18,200' (MD) contribute to flow, the time required to build-up to a static SIWHP is essentially the same as the cases listed above in items 4) a. and 4) b.

6) The expected reservoir pressure depletion ranges from 40 psia (assuming a production rate of 5,000 bopd) to 400 psia (assuming a production rate of 60,000 bopd) from April 20 to May 14, 2010. This depletion would reduce the SIWHP by an equivalent amount.

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**Discussion**

**Shut-in Wellhead Pressure (SIWHP)**

All SIWHP calculations are based on a static formation pressure measured by MDT (11,850 psia at 18,124' MDRKB) and PVT lab analyses from Pencor and Schlumberger. The PVT lab analyses were conducted on MDT samples taken at 18,142' MDRKB. We have conducted QA/QC on the samples and are satisfied that they represent the reservoir fluid. The two vendors' results are consistent with each other with respect to a single phase fluid. Tests are ongoing as of May 14, 2010 on two additional samples taken at depths: 18,086' MDRKB and 18,142' MDRKB.

A summary of SIWHP calculation methods and results follows:

- 8,900 psia (PIPESIM) steady-state model (Farah Saidi, April 29th, 2010).
- 8,835 psia (PROSPER) Lasater correlation steady-state model (Tony Liao, May 14, 2010).
- 8,600 psia (OLGA v5.3.2) transient model (Farah Saidi, ~April 29th, 2010) considered accurate to within +/- 200 psia.
- 8,550 psia (PROSPER) Vasquez-Beggs correlation steady-state model (Simon Bishop, May 13, 2010)
- 8,400 psia (OLGA v5.3) compositional, transient model (Ole Rygg, add energy, May 13, 2010)

Black-Oil PVT tables were generated in PROSPER software using reference values of Oil Gravity (35 °API,) GOR (2,900 scf/stb,) Pbp (6,650 psig,) Reservoir Temperature (240 °F) and initial Reservoir Pressure (11,850 psig.)

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**Pressure Build-up Time**

The reservoir pressure transient calculations were performed using the PIE pressure transient analysis software. Two reservoir models were used:

> 1) a single oil layer ($k_o$= 300mD, h= 88ft, A= 3,500' x 8,000', $\phi$= 21%, $S_w$= 12.3%, $c_o$= 14.6 $\mu$sips, $\mu_o$= 0.168 cP, $B_o$= 2.77rb/stb, $P_{ri}$= 11,850 psia)

> 2) two layers, the first identical to the previously described oil layer and the 2$^{nd}$ mimicking a gas layer which has the same areal extent, water saturation and porosity, h= 3ft, $k_g$= 15 mD (equiv. $k_o$= 72mD) and $P_{ri}$= 12,028 psia. Model 2 incorporates cross-flow between the two layers in the wellbore. Initial model date was May 3, 2010.

The wellbore portion of the pressure calculations were performed using OLGA software with the bottom-hole pressure calculations from PIE as a boundary condition.

**Reservoir Depletion**

Reservoir pressure depletion due to production was evaluated using the MBal software. Model inputs included: 11850 psi initial reservoir pressure, 188 mmstb original oil in place (based on volumetric calculations,) no aquifer, no gas cap, $S_w$=15%, $c_f$= 6 $\mu$sips $c_w$= 4.5 $\mu$sips; Corey exponents and endpoints of 1.2 and 0.63 for water, 2 and 0.8 for oil, 1.5 and 0.9 for gas.

Three constant production rate scenarios at 5, 20 and 60 mbopd were evaluated. For the time period from April 20 – May 14, 2010, the expected depletion is 40 psi for the 5 mbopd case and 400 psi for the 60 mbopd case.

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## Appendix

## Reservoir Description

### Macondo Sand Identification
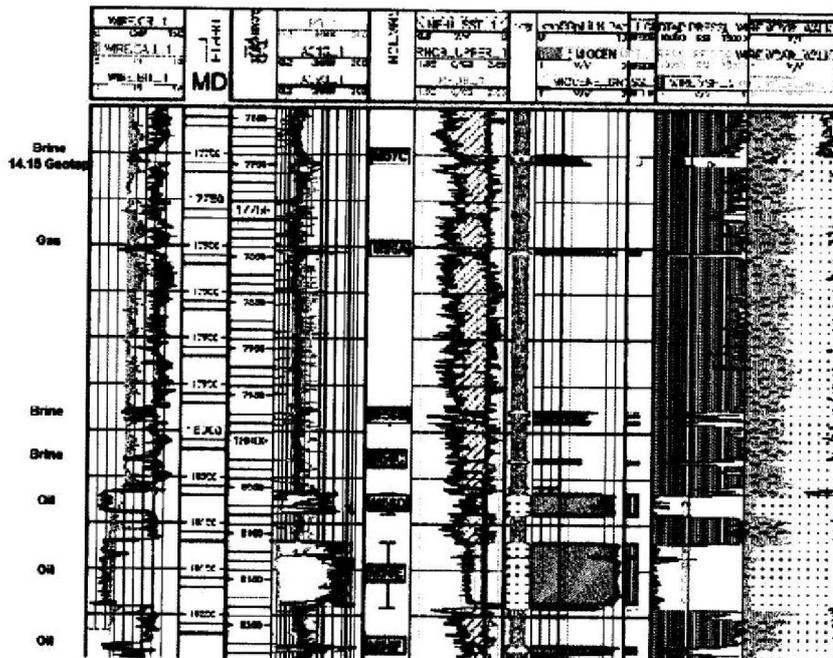


### Current Available Pressure Measurements and Well Conditions
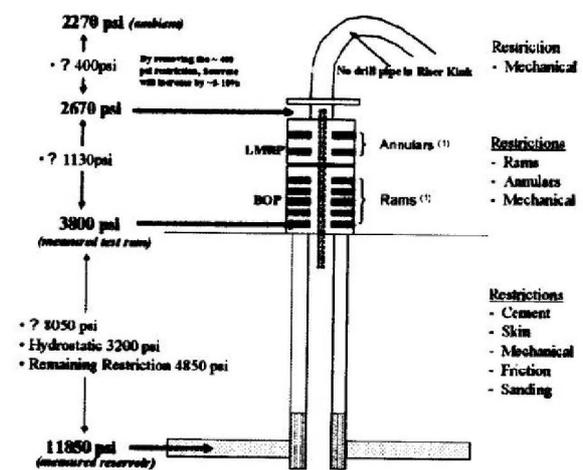


### Single layer oil Reservoir Pressure Build-up Cases

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Figure showing Shut-in / Buildup pressure plots:
- Shut-in
- Buildup — 300 mD, s=0. BU time = 5 min
- 170 mD, s=0. BU time= 15 min
- 300 mD, s=50. BU time= 30 min
- Shut-in at 600 hours (25 days)

pressure PSI axis: 11500, 11000, 10500
rates STBD axis: 4000, 2000, -1000
Time axis: 599.50, 600.00, 600.50, 601.00, 601.50

**Time, hours**
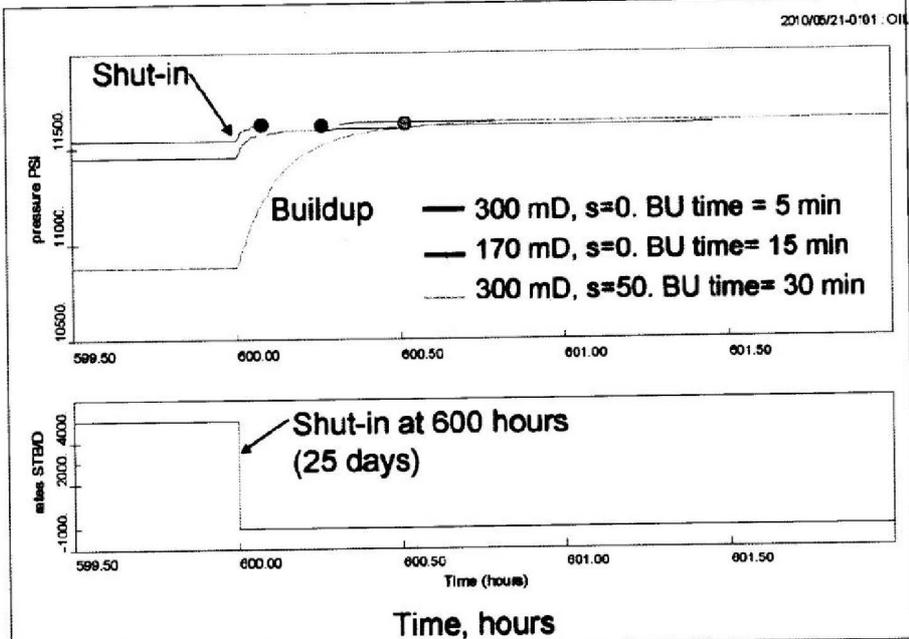
Homogeneous Reservoir

```
** Simulation Data **                         Static-Data and Constants
well. storage  = 0.10000        BBLS/PSI      Volume-Factor  = 2.770  vol/vol
skin           =    0.    50.000 ()           Thickness      = 88.00  FEET
permeability   =  300.00 170.00 MD            Viscosity      = 0.1780 CP
Areal Ky/Kx    = 1.0000         ()            Total Compress = .1917E-04 1/PSI
Perm-Thickness =  26400. 14980. MD-FEET       Rate           = 5000. STB/D
 x boundary    =  1750.         FEET          Storivity      = 0.0003543 FEET/PSI
-x boundary    =     1.00       FOG-FACTOR    Diffusivity    = 110400. FEET^2/HR
-x boundary    =  1750.         FFET          Gauge Depth    = N/A FEET
-y boundary    =     1.00       FOG-FACTOR    Perf. Depth    = N/A FEET
 y boundary    =  4000.         FEET          Datum Depth    = N/A FEET
-y boundary    =     1.00       FOG-FACTOR    Analysis-Data  ID: DATA
-y boundary    =  2000.         FFET          PFA Starts: 2010-04-26 01:01:01
-y boundary    =     1.00       FOG-FACTOR    PFA Ends  : 2010-06-10 21:01:01
Initial Press. = 11850.0        PSI
Average Press. = 11654.0        PSI
```

**Comparison of Single Layer Oil and Two Layer Oil & Gas Reservoir Pressure Build-up Cases**

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2010/05/21-0101 : OIL



**Buildup**   Oil & Gas with Cross-flow through Wellbore

**Shut-in**

*Delta P = 6 psi between single layer oil only model and two layer oil/gas model.*

Oil reservoir only

—— **Two layer model**

········ **Single layer model**

pressure PSI

11650

11600

11550

11500

599.50    600.00    600.50    601.00    601.50

**Shut-in at 600 hours (25 days)**

rates STB/D

4000
2000
-1000

599.50    600.00    600.50    601.00    601.50

Time (hours)

Two-layer Reservoir with NO Cross-flow and Limits

```
** Simulation Data **                    Type-Curve Model Static-Data
well. storage  =   0.10000 BBLS/PSI      'Wall' Thick.  = 0. FEET
Skin(1)        =   0.                    Layer-1 Thick. = 3.00 FEET
Skin(2)        =   0.                    Layer-2 Thick. = 88.0 FEET
permeability-1 =   72.000 MD
permeability-2 =   300.00 MD             Static-Data and Constants
omega          =   0.032967             Volume-Factor = 2.770 vol/vol
layer (P2-P1)  =   -138.00 PSI          Thickness     = 91.00 FEET
Perm-Thickness =   26616. MD-FEET       Viscosity     = 0.1680 CP
+x boundary(1) =   1750. FEET (1.00)    Total Compress = .1917E-04 1/PSI
-x boundary(1) =   1750. FEET (1.00)    Rate          = 5000. STB/D
+y boundary(1) =   4000. FEET (1.00)    Storivity     = 0.0003664 FEET/PSI
-y boundary(1) =   4000. FEET (1.00)    Diffusivity   = 114000. FEET^2/HR
+x boundary(2) =   1750. FEET (1.00)    Gauge Depth   = N/A FEET
-x boundary(2) =   1750. FEET (1.00)    Perf. Depth   = N/A FEET
+y boundary(2) =   4000. FEET (1.00)    Datum Depth   = N/A FEET
-y boundary(2) =   4000. FEET (1.00)    Analysis-Data  ID: DATA
Initial Press. =   12028.0 PSI          PFA Starts: 2010-04-26 01:01:01
Average Press. =   11666.4 PSI          PFA Ends  : 2010-05-25 05:01:01
Pore-Volume    =   .5351E+09 FEET^3
```

**Wellhead Pressure Build-up Cases**

Shut-in with 5000 bpd choked back (annulus)

Page **Shallow choke**        Confidential **Deep choke** E \@ "M/d/yyyy" }

Shut-in,    13000

Shut-in,    13000
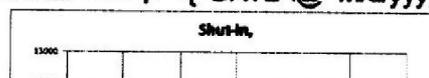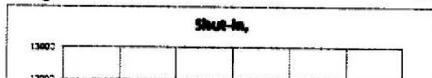
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(Source: Ole Rygg, add energy)

**Summary of Pressure Depletion Calculations**



Macondo 1
Expected Reservoir Depletion (MBAL Model)

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