From: Suttles, Doug J
Sent: Wed May 19 16:43:10 2010
To: Lynch, John E Jr. (Jack); Inglis, Andy G (UPSTREAM)
Subject: FW: Flow rate note?
Importance: Normal
Attachments: rate summary.doc; rate summary attachments.pdf

FYI

Doug

Doug Suttles

Chief Operating Officer

Exploration & Production

BP

From: Suttles, Doug J

Sent: Wednesday, May 19, 2010 11:42 AM

To: Admiral Mary Landry (mary.e.landry@uscg.mil); Admiral Thad Allen (Thad.W.Allen@uscg.mil)

Cc: James A. Watson IV (james.a.watson@uscg.mil); Admiral Neffenger (peter.v.neffenger@uscg.mil)

Subject: FW: Flow rate note?

Admiral Allen and Admiral Landry,
Attached below is our most recent work on flow rate estimation. Don't hesitate to contact me if you would like to discuss.
Doug

Doug Suttles

Chief Operating Officer

Exploration & Production

BP

From: Rainey, David I

Sent: Wednesday, May 19, 2010 12:47 AM

To: Suttles, Doug J

Subject: RE: Flow rate note?

<<...>> <<...>>

Apologies Doug - had to run for plane. Initial info was meeting 1:00 pm Wed.. At 4:00 pm got word mtg was 9:00 am!
Dave

From: Suttles, Doug J

Sent: Tuesday, May 18, 2010 11:43 PM

To: Rainey, David I

Subject: Flow rate note?

Doug Suttles

6201
Exhibit No. ______
Worldwide Court Reporters, Inc.

Mississippi Canyon 252 #1
Flow Rate Calculations

Context
A 30 second video clip of hydrocarbons leaking from the broken end of the Deepwater Horizon drilling riser has been released to the public. Various "experts" are challenging Unified Command's best guess estimate of flow rate at the seabed based on this video clip. This note summarizes the various estimates that have been made within Unified Command.

Mass Balance
The mass balance calculation involves estimating, through visual inspection, the volume of oil on the surface of the water. Allowances are then made for natural dispersion and evaporation. Estimates of volumes skimmed, burned, and chemically dispersed then allow an estimate of the oil released at the seabed over the duration of the spill. The calculation is repeated each day weather permitting.

In the early days of the spill, the surface expression of the spill was relatively small. Overflights were able to provide fidelity with respect to the character of the oil on the surface. Three descriptors were used

- Sheen
- Dull
- Dark oil

There are two Standards for estimating the thickness of oil on water using visual descriptors.

- US-based ASTM Standard
- European-based Bonn Agreement

The visual descriptors are different in the two standards and the relationships to thickness are also different.

From April 27 through April 30 daily estimates of flow rate were made on the basis of visual description of the oil on the surface. Three estimates were made each day – low, best guess, and high – to allow for differences between the two standards, and uncertainties around the input parameters.

- Low end was always around 1,000 barrels per day
- Best guess was between 5,000 and 6,000 barrels per day
- High end varied from 12,000 to 14,000 barrels per day

The tables associated with these estimates are attached (Attachments 1-4). These estimates played an important part in Unified Command's decision to raise the estimate of flow rate from 1,000 to 5,000 barrels per day.

During the storm which began on May 1, and for several days after, no visual description of the spill was obtained. From May 8, daily outlines of the spill have been available based on a combination of satellite and aerial overflights. However, because of the size of the spill area, overflights have been unable to provide fidelity on the visual appearance of the oil within the spill area. During the five days in April for which fidelity was available, the ratios of dark oil to dull oil to sheen remained relatively constant at 2/10/88. These ratios have been applied to the total area of spill on May 17. Current estimates of volumes of oil skimmed, burned, and chemically dispersed were then applied to provide an updated range of possible flow rates as follows: 2,000 – 6,000 – 13,000 barrels per day (Attachment 5).

Note that all serious scientists recognize that there are huge uncertainties in estimating oil volumes from visual inspection. Oil thickness is by far the greatest uncertainty, with both sheen and darker oil thicknesses varying by orders of magnitude.

Maximum Discharge Calculation
Prior to drilling the MC 252 exploration well a maximum discharge estimate was provided as part of the permitting process. Predictions of reservoir thickness, quality, and pressure were convolved with the well design to develop a worse case scenario as follows.

- Optimistic assumptions for reservoir thickness, quality, pressure, and fluid properties.
- Total loss of control of well after drilling through reservoir in largest hole size allowed by the well design – 12 ¼".
- Totally uncontrolled flow from drilling riser at surface.

Using these assumptions, a maximum case discharge of 162,000 barrels per day was estimated.

After the sinking of the Deepwater Horizon, this estimate was reviewed in the light of the actual situation as it was understood at that time.

- Formation evaluation of the reservoir interval.
- 9 7/8" hole size in the reservoir
- 7" production tubing across the reservoir
- Flow to seabed through casing annulus
- Split 5 ½" drill pipe at BOP and flow out 6 5/8" drill pipe
- No restrictions in BOP, riser, or drill pipe (ie well head open to seabed – requires BOP to fall off well head)

An absolute worst case flow rate of 60,000 barrels per day was calculated. A more reasonable worst case scenario of 40,000 barrels per day recognizes the following.

- BOP is in place and may be partially activated.
- The riser and drill pipe is crushed and kinked.
- Restrictions provided by cement in the casing annulus, formation collapse, casing hangers, etc., are likely.

This analysis is summarized on Attachment 6.

A more sophisticated version of this calculation has been carried out as more has been learned about pressures at the top and bottom of the well head. This review calculates unconstrained flow rate through the casing as well as up the annulus. Absolute worst cases with wellhead and BOP removed, and no downhole restrictions, are as follows (Attachment 7).

- Annular flow – 55,000 barrels per day
- Casing flow – 100, 000 barrels per day

Fluid Velocity At Seabed

On April 26, NOAA scientists made an estimate of volume release rate at the seabed as follows.

- Oil leaking from a hole approximately 40 cm in diameter (Deepwater Horizon riser is 19.5"/49.5 cm ID, and is somewhat crimped at release point).
- By visual inspection the velocity of the material in the plume is between 7 and 30 cm per second.
- The plume contains roughly 50% oil droplets (together with gas bubbles and entrained seawater).

The NOAA estimate using these assumptions was roughly 5,000 barrels per day (Attachment 8).

Evidence Against Extreme Flow Rates At Seabed
A Professor from Purdue University has calculated a current flow rate at the seabed of 70,000 +/- 14,000 barrels per day. He bases his estimate on the velocity of fluid exiting the drilling riser on the seabed. His estimate is unlikely to allow for the following additional factors required to estimate the flow of oil.

- Drill pipe in riser reducing flow area
- Partial crimping of riser end reducing flow area
- Proportion of gas and entrained water exiting riser with the oil
- Volume reduction of oil as gas escapes en route from seabed to surface
- Flow rate not constant

Finally, there is absolutely no evidence of any floating material being entrained in the plume exiting the broken riser. In a report to the MMS on Oil Spill Containment, Remote Sensing and Tracking For Deepwater Blowouts, PCCI Marine and Environmental Engineering made the following statement.

> *"The blowout plume will make it difficult to approach the well with anything but very massive equipment pieces or ROVs. The operation of ROVs will be difficult around the blowout point. The jet zone will cause vast amounts of water to flow towards the well. The danger of having lighter equipment sucked into the flow is large. Many ROVs have been rendered useless by relatively minor blowout plumes"*

ROV video shows neutrally buoyant material passing within inches of the plume without being sucked in. From this observation alone, the flow velocity must be relatively low.

Chief Operating Officer

Exploration & Production

BP

Using "Standard Guide for Visually Estimating Oil Spill Thickness on Water, ASTM F 2534 - 06."

ATTACHMENT 1

Oil on Water Estimate - Low

	sq mi	Cover Factor	gal/sq mi	gals	bbls
Sheen	1500	0.5	50	37500	893
Dull oil	250	0.2	666	33300	793
Dark oil	9	0.15	3330	4495.5	107

Total oil on water	75296	1793
x 2 to compensate for evap and disp		3586
recovered		200
chemically dispersed		1000
Total emitted		4786
Barrels emitted per day		**1063**

Oil on Water Estimate - Best Guess

	sq mi	Cover Factor	gal/sq mi	gals	bbls
Sheen	1500	0.66	333	329670	7849
Dull oil	250	0.35	1332	116550	2775
Dark oil	9	0.25	6660	14985	357

Total oil on water	461205	10981
x 2 to compensate for evap and disp		21962
recovered		450
chemically dispersed		3500
Total emitted		25912
Barrels emitted per day		**5758**

Oil on Water Estimate - High

	sq mi	Cover Factor	gal/sq mi	gals	bbls
Sheen	1500	0.75	666	749250	17839
Dull oil	250	0.5	3330	416250	9911
Dark oil	9	0.35	13320	41958	999

Total oil on water	1E+06	28749
x 2 to compensate for evap and disp		57498
recovered		700
chemically dispersed		6000
Total emitted		64198
Barrels emitted per day		**14266**

ATTACHMENT 2

Using "Standard Guide for Visually Estimating Oil Spill Thickness on Water, ASTM F 2534 - 06 "

Oil on Water Estimate - Low

	sq mi	Cover Factor	gal/sq m	gals	bbls
Sheen	1641	0.5	50	41025	977
Dull oil	235	0.2	666	31302	745
Dark oil	21	0.15	3330	10490	250

Total oil on water	82817	1972
x 2 to compensate for evap and disp		3944
recovered		200
chemically dispersed		1000
Total emitted		5144
Barrels emitted per day		**935**

Oil on Water Estimate - Best Guess

	sq mi	Cover Factor	gal/sq m	gals	bbls
Sheen	1641	0.66	333	360659	8587
Dull oil	235	0.35	1332	109557	2609
Dark oil	21	0.25	6660	34965	833

Total oil on water	505181	12028
x 2 to compensate for evap and disp		24056
recovered		450
chemically dispersed		3500
Total emitted		28006
Barrels emitted per day		**5092**

Oil on Water Estimate - High

	sq mi	Cover Factor	gal/sq m	gals	bbls
Sheen	1641	0.75	666	819680	19516
Dull oil	235	0.5	3330	391275	9316
Dark oil	21	0.35	13320	97902	2331

Total oil on water	1308857	31163
x 2 to compensate for evap and disp		62327
recovered		700
chemically dispersed		6000
Total emitted		69027
Barrels emitted per day		**12550**

ATTACHMENT 3

Using "Standard Guide for Visually Estimating Oil Spill Thickness on Water, ASTM F 2534 - 06."

Oil on Water Estimate - Low

	sq mi	Cover Factor	gal/sq mi	gals	bbls
Sheen	1929	0.5	50	48225	1148
Dull oil	238	0.2	666	31702	755
Dark oil	91	0.15	3330	45455	1082
Total oil on water				125381	2985
x 2 to compensate for evap and disp					5971
recovered					400
chemically dispersed					1400
Total emitted					7771
Barrels emitted per day					**1195**

Oil on Water Estimate - Best Guess

	sq mi	Cover Factor	gal/sq mi	gals	bbls
Sheen	1929	0.66	333	423956	10094
Dull oil	238	0.35	1332	110956	2642
Dark oil	91	0.25	6660	151515	3608
Total oil on water				686426	16343
x 2 to compensate for evap and disp					32687
recovered					1500
chemically dispersed					4200
Total emitted					38387
Barrels emitted per day					**5906**

Oil on Water Estimate - High

	sq mi	Cover Factor	gal/sq mi	gals	bbls
Sheen	1929	0.75	666	963536	22941
Dull oil	238	0.5	3330	396270	9435
Dark oil	91	0.35	13320	424242	10101
Total oil on water				1784048	42477
x 2 to compensate for evap and disp					84955
recovered					3000
chemically dispersed					6000
Total emitted					93955
Barrels emitted per day					**14455**

4/29/10

ATTACHMENT 4

Using "Standard Guide for Visually Estimating Oil Spill Thickness on Water, ASTM F 2534 - 06"

Oil on Water Estimate - Low

	sq mi	Cover Factor	gal/sq m	gals	bbls
Sheen	2481	0.5	50	62025	1477
Dull oil	160	0.2	666	21312	507
Dark oil	35	0.15	3330	17483	416

Total oil on water	100820	2400
x 2 to compensate for evap and disp		4801
recovered		500
chemically dispersed		1600
Total emitted		6901
Barrels emitted per day		**920**

Oil on Water Estimate - Best Guess

	sq mi	Cover Factor	gal/sq m	gals	bbls
Sheen	2481	0.66	333	545274	12983
Dull oil	160	0.35	1332	74592	1776
Dark oil	35	0.25	6660	58275	1388

Total oil on water	678141	16146
x 2 to compensate for evap and disp		32292
recovered		2000
chemically dispersed		4900
Total emitted		39192
Barrels emitted per day		**5226**

Oil on Water Estimate - High

	sq mi	Cover Factor	gal/sq m	gals	bbls
Sheen	2481	0.75	666	1239260	29506
Dull oil	160	0.5	3330	266400	6343
Dark oil	35	0.35	13320	163170	3885

Total oil on water	1668830	39734
x 2 to compensate for evap and disp		79468
recovered		4000
chemically dispersed		7200
Total emitted		90668
Barrels emitted per day		**12089**

Attachment 5

Using "Standard Guide for Visually Estimating Oil Spill Thickness on Water, ASTM F 2534 - 06."

Oil on Water Estimate - Low

	sq mi	Cover Factor	gal/sq mi	gals	bbls
Sheen	5256	0.5	50	131400	3129
Dull oil	597	0.2	666	79520.4	1893
Dark oil	120	0.15	3330	59940	1427

Total oil on water	270860.4	6449
x 2 to compensate for evap and disp		12898
recovered		15838
chemically dispersed		16500
burned		5821
Total emitted		51057
Barrels emitted per day		**1891**

Oil on Water Estimate - Best Guess

	sq mi	Cover Factor	gal/sq mi	gals	bbls
Sheen	5256	0.66	333	1155164	27504
Dull oil	597	0.35	1332	278321.4	6627
Dark oil	120	0.25	6660	199800	4757

Total oil on water	1633285	38888
x 2 to compensate for evap and disp		77775
recovered		31676
chemically dispersed		33000
burned		11642
Total emitted		154093
Barrels emitted per day		**5707**

Oil on Water Estimate - High

	sq mi	Cover Factor	gal/sq mi	gals	bbls
Sheen	5256	0.75	666	2625372	62509
Dull oil	597	0.5	3330	994005	23667
Dark oil	120	0.35	13320	559440	13320

Total oil on water	4178817	99496
x 2 to compensate for evap and disp		198991
recovered		63352
chemically dispersed		66000
burned		23284
Total emitted		351627
Barrels emitted per day		**13023**

ATTACHMENT 6

Seafloor Exit
7" x 9-7/8" Casing Annulus Flow Path

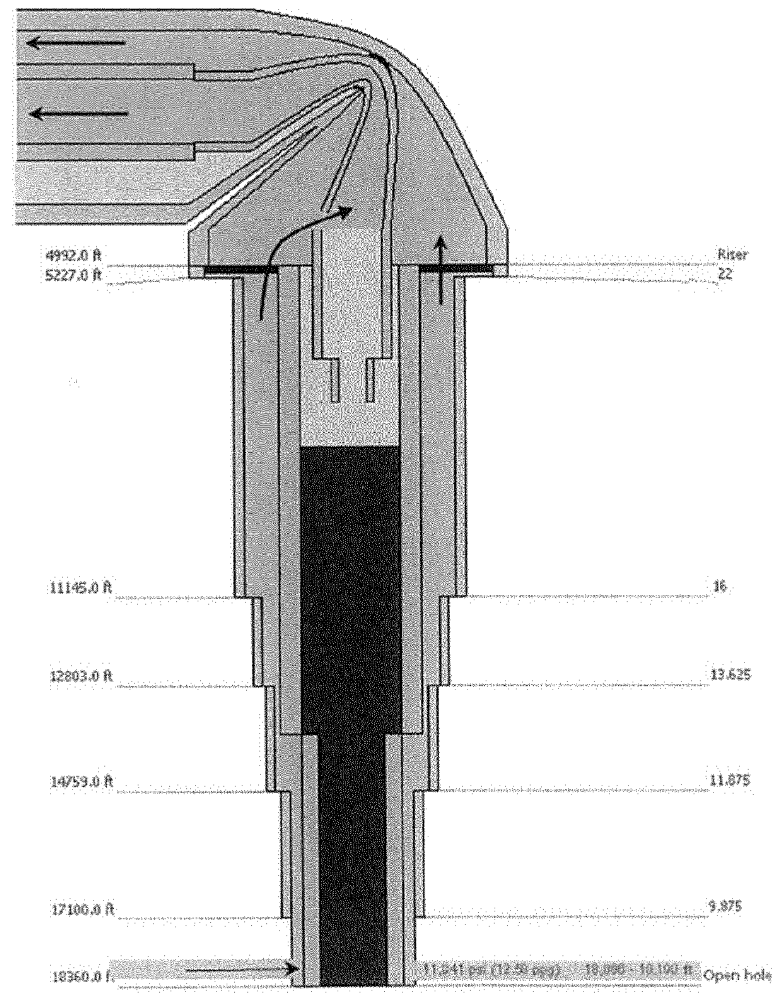
Worst case theoretical flow assumes:

- Split 5-1/2" drill pipe at subsea BOP and flow out 6-5/8" drill pipe
- Maximum theoretical flow rate is 60,000 BOPD

Items that reduce worst case theoretical flow:

- Crushed and bent riser and drill pipe
- Cement sheath in open hole by casing annulus
- Casing hanger and pack-off restriction
- Sand production (unconsolidated formation)
- Shale collapse
- Water production
- BOP functions activated
- Expected range of possible flow rates is 5,000 to 40,000 BOPD

NOTE: Removal of all restrictions (riser, BOP, and drill pipe) adds ~10,000 BOPD to rates above



ATTACHMENT 7

Key Messages

Expected Case:

In the current state a wellhead pressure decrease from 3800 psi to 2270 psi (pressure seafloor) results in a flow rate increase ranging from 15% to 30%

Alternate Case:

If fluid flow is only through the drill pipe – and then the drill pipe is unintentionally removed and flows into the sea (2270 psi):

- For flow up the annulus the rate doubles
- For flow inside production casing the rate triples

Note:

If BOP and wellhead are removed and if we have incorrectly modeled the restrictions – the rate could be as high as ~ 100,000 barrels per day up the casing or 55,000 barrels per day up the annulus (low probability worst cases)

ATTACHMENT 8

Estimation of the Oil Released from Deepwater Horizon Incident
(26 April 2010, 1200hrs PDT)

1) **Surface Oil volume Estimation**

Estimating oil volume by the visual appearance of the slick is a highly unreliable process. At best, one can calculate an answer to only an order of magnitude. Other estimation methods, if available, are likely to give more accurate answers

Oil spills separate into thick portions that can be as thick as an inch or more and thin sheen that are only as thick as a few visible light wavelengths. Most of the oil volume in a typical crude oil spill is in the thick part (but most of the area is sheen

Much of the oil from the light crude that is being released will evaporate or disperse in the water column. We would expect at least half of the oil released to be accounted for by these mechanisms

The oil that makes it to the surface is showing signs of emulsification. Emulsified oil can contain up to 90% water.

Weathered oil that has formed tar balls are not detectable by satellites or overflights.

Based upon past experiments, published standards, and actual spills, NOAA/ERD defines the range of thickness of slicks as

Sheen thickness – $(10^{-8}m \leftrightarrow 10^{-5}m)$
Dark oil thickness- $(10^{-5}m \leftrightarrow 10^{-2}m)$ 1 cm

Area coverage of slick (4/26/10), based upon satellite images $(1500km^2 \leftrightarrow 3000km^2)$

Sheen volume, using average thickness of 0.1 micron, area of 2000 sq. km and 100% coverage yields oil volume of 200 cu. m = 1200 bbl= 50,000 gal

Thick oil volume, using average thickness of 100 microns, 1% average coverage and 50% water content yields an oil volume of 1000 cu. m = 6000 bbl. = 0.25 million gal

To an order of magnitude, we estimate that there are around 10,000 bbl of oil on the water surface, or around a half million gallons

2) **Estimated Present Volume Release Rate**

The following assumptions are used to make a release rate calculation. If any of them are changed, the answer could be significantly different.

The oil is leaking, in a vertical plume from a hole approximately 40 cm. in diameter.

The velocity of the material in the plume is estimated by visual observation to be between 7 cm/sec and 30 cm/sec.

The plume itself contains gas bubbles, oil droplets, and entrained seawater.

4 Assuming that 50% of the plume volume is oil and a rise velocity of 15 cm/sec, the oil released from this source would be roughly 5000 bbl/day. (approximately 200,000 gal/day) Other sources would contribute additional oil. This answer will be refined as additional information becomes available.