Blowout Prevention and Relief Well Planning for the Wheatstone Big-Bore Gas Well Project

(SPE 174890 – Sep 2017 SPE Drilling & Completions)

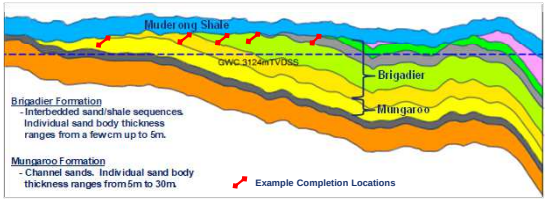
Eric R. Upchurch, Chevron Brazil Ltd.

28 March 2018

Poll Question

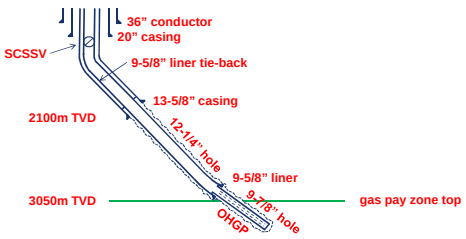
In what region of the world is the project you are presently working on?

Wheatstone Geologic Cross-Section



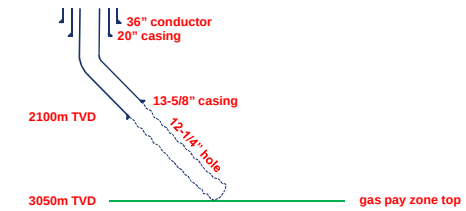
- Brigadier: k_h = 1.5 darcies & k_v/k_h = 0.1
- Mungaroo: k_h = 8 darcies & k_v/k_h = 0.9

Wheatstone Well Design

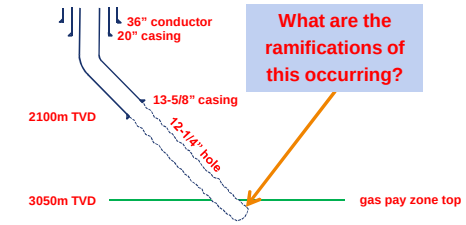


4

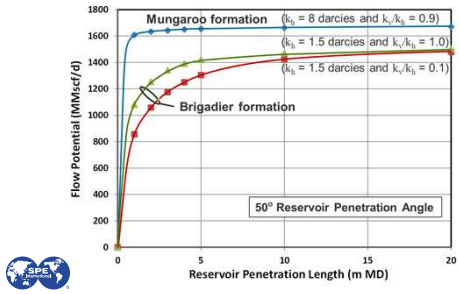
Wheatstone Well Design



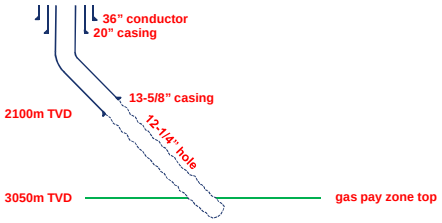
Wheatstone Well Design



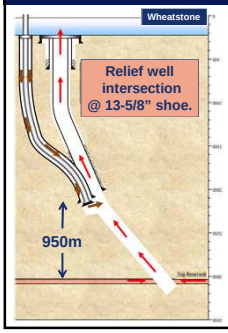
Blowout Rate vs Reservoir Penetration



Wheatstone Well Design



Dynamic Kill Simulation Results
13-5/8" Casing Shoe Relief Well Intersection



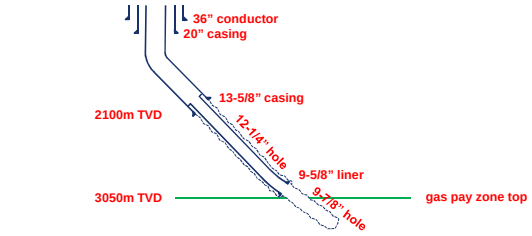
Results

- 1.3 – 1.9 Bcfd blowout rate
- *204 – 238 bpm* of 15 ppg mud required to effect a kill

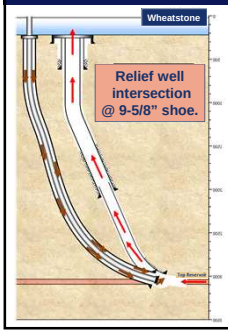
Issues

- Three to four relief wells are required:
  - Assumes a single relief well can inject 60 -100 bpm of kill fluid

Wheatstone Well Design



Dynamic Kill Simulation Results
9-5/8" Shoe Relief Well Intersection



Results

- 0.9 – 1.0 Bcfd blowout rate
- *99 bpm* of 15 ppg mud required to effect a kill

Issues

- One to two relief wells are required:
  - Assumes a single relief well can inject 60 -100 bpm of kill fluid

Blowout Well Name (country)		BOP Type		Maximum Reported Pumping Rate (for a single well)	Fluid Density & Type
Arun C-II-2 (Indonesia)		Surface BOP		126 bpm	8.5 ppg water
Cox No. 1 (United States)		Surface BOP		43 bpm	8.5 ppg water
El Isba 123 (Syria)		Surface BOP		120 bpm	8.5 ppg water
Enchova 19D (Brazil)	2 RWs (intercept)	Subsea BOP	success	72 bpm	8.5 ppg water
Fateh L-3 (Dubai)	4 RWs (proximity)	Surface BOP	failure	160 bpm	8.5 ppg water
Ixtoc No. 1 (Mexico)	2 RWs (proximity)	Surface BOP	failure	100 bpm	8.5 ppg water
Sheep Mountain 4-15-H (United States)		Surface BOP		60 bpm	10.5 ppg brine
West Cameron 165 No. 3 (United States)		Surface BOP		75 bpm	8.5 ppg water
Well 159 (Bahrain)		Surface BOP		10 bpm	11.6 ppg mud

Blowout Well Name (country)		BOP Type		Maximum Reported Pumping Rate (for a single well)	Fluid Density & Type
Arun C-II-2 (Indonesia)		Surface BOP		126 bpm	8.5 ppg water
Cox No. 1 (United States)		Surface BOP		43 bpm	8.5 ppg water
El Isba 123 (Syria)		Surface BOP		120 bpm	8.5 ppg water
Enchova 19D (Brazil)	2 RWs (intercept)	Subsea BOP	success	72 bpm	8.5 ppg water
Fateh L-3 (Dubai)	4 RWs (proximity)	Surface BOP	failure	160 bpm	8.5 ppg water
Ixtoc No. 1 (Mexico)	2 RWs (proximity)	Surface BOP	failure	100 bpm	8.5 ppg water
Sheep Mountain 4-15-H (United States)		Surface BOP		60 bpm	10.5 ppg brine
West Cameron 165 No. 3 (United States)	1 RW (proximity)	Surface BOP	success	75 bpm	8.5 ppg water
Well 159 (Bahrain)		Surface BOP		10 bpm	11.6 ppg mud

Blowout Well Name (country)		BOP Type		Maximum Reported Pumping Rate (for a single well)	Fluid Density & Type
Arun C-II-2 (Indonesia)	1 RW (intercept)	Surface BOP	success	126 bpm	8.5 ppg water
Cox No. 1 (United States)		Surface BOP		43 bpm	8.5 ppg water
El Isba 123 (Syria)	1 RW (intercept)	Surface BOP	success	120 bpm	8.5 ppg water
Enchova 19D (Brazil)	2 RWs (intercept)	Subsea BOP	success	72 bpm	8.5 ppg water
Fateh L-3 (Dubai)	4 RWs (proximity)	Surface BOP	failure	160 bpm	8.5 ppg water
Ixtoc No. 1 (Mexico)	2 RWs (proximity)	Surface BOP	failure	100 bpm	8.5 ppg water
Sheep Mountain 4-15-H (United States)		Surface BOP		60 bpm	10.5 ppg brine
West Cameron 165 No. 3 (United States)	1 RW (proximity)	Surface BOP	success	75 bpm	8.5 ppg water
Well 159 (Bahrain)	1 RW (intercept)	Surface BOP	success	10 bpm	11.6 ppg mud

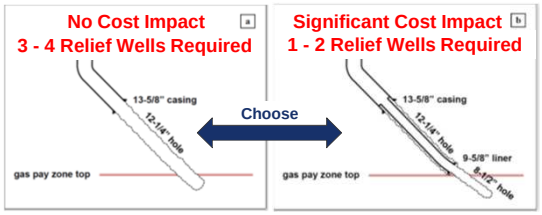
Blowout Well Name (country)		BOP Type		Maximum Reported Pumping Rate (for a single well)	Fluid Density & Type
Arun C-II-2 (Indonesia)	1 RW (intercept)	Surface BOP	success	126 bpm	8.5 ppg water
Cox No. 1 (United States)	1 RW (perforate)	Surface BOP	success	43 bpm	8.5 ppg water
El Isba 123 (Syria)	1 RW (intercept)	Surface BOP	success	120 bpm	8.5 ppg water
Enchova 19D (Brazil)	2 RWs (intercept)	Subsea BOP	success	72 bpm	8.5 ppg water
Fateh L-3 (Dubai)	4 RWs (proximity)	Surface BOP	failure	160 bpm	8.5 ppg water
Ixtoc No. 1 (Mexico)	2 RWs (proximity)	Surface BOP	failure	100 bpm	8.5 ppg water
Sheep Mountain 4-15-H (United States)		Surface BOP		60 bpm	10.5 ppg brine
West Cameron 165 No. 3 (United States)	1 RW (proximity)	Surface BOP	success	75 bpm	8.5 ppg water
Well 159 (Bahrain)	1 RW (intercept)	Surface BOP	success	10 bpm	11.6 ppg mud

Blowout Well Name (country)		BOP Type		Maximum Reported Pumping Rate (for a single well)	Fluid Density & Type
Arun C-II-2 (Indonesia)	1 RW (intercept)	Surface BOP	success	126 bpm	8.5 ppg water
Cox No. 1 (United States)	1 RW (perforate)	Surface BOP	success	43 bpm	8.5 ppg water
El Isba 123 (Syria)	1 RW (intercept)	Surface BOP	success	120 bpm	8.5 ppg water
Enchova 19D (Brazil)	2 RWs (intercept)	Subsea BOP	success	72 bpm	8.5 ppg water
Fateh L-3 (Dubai)	4 RWs (proximity)	Surface BOP	failure	160 bpm	8.5 ppg water
Ixtoc No. 1 (Mexico)	2 RWs (proximity)	Surface BOP	failure	100 bpm	8.5 ppg water
Sheep Mountain 4-15-H (United States)	1 RW	Surface BOP	success	60 bpm	10.5 ppg brine
West Cameron 165 No. 3 (United States)	1 RW (proximity)	Surface BOP	success	75 bpm	8.5 ppg water
Well 159 (Bahrain)	1 RW (intercept)	Surface BOP	success	10 bpm	11.6 ppg mud

Reservoir Entry Decision Drivers

Webinars

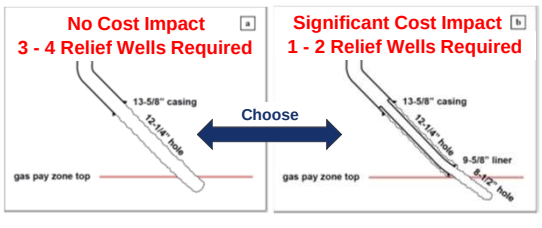
- No industry precedents for simultaneously utilizing multiple subsea relief wells to dynamically kill a blowout with weighted fluid



Reservoir Entry Decision Drivers

Webinars

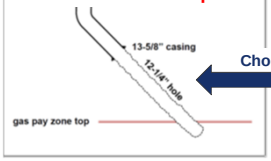
- Only one industry example exists for utilizing two subsea relief wells to dynamically kill a blowout with water (Enchova 19D – Brazil 1989)



Reservoir Entry Decision Drivers

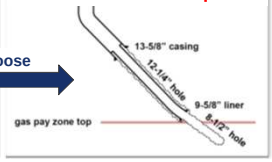
- The magnitude of a Wheatstone blowout could impact our reputation as an industry-leading safe operator

No Cost Impact
3 - 4 Relief Wells Required



Choose

Significant Cost Impact
1 - 2 Relief Wells Required



Risk-Based Decision Mathematics

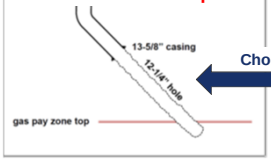
$$\infty \cdot 0 =$$

Cost — Chance of Occurrence

- The traditional mathematics of risk-based decision making do not apply for risks that risk more than money.
  - What is the long term value of your company's reputation?
    - Difficult question to answer!

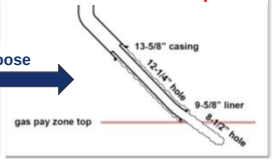
Reservoir Entry Decision Drivers

No Cost Impact
3 - 4 Relief Wells Required

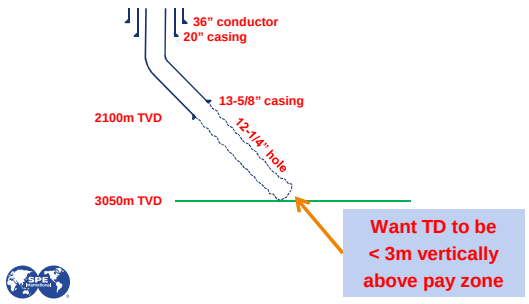


Choose

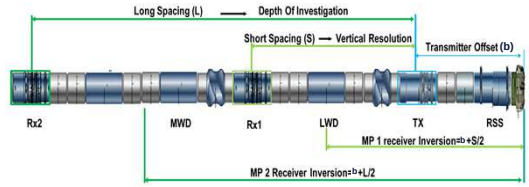
Significant Cost Impact
1 - 2 Relief Wells Required



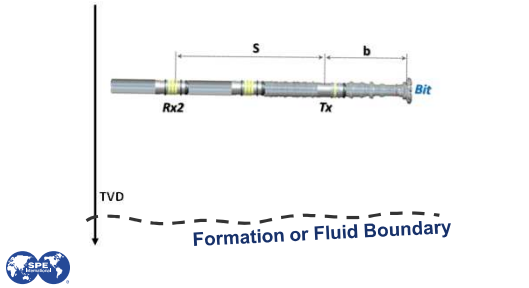
Wheatstone Well Design

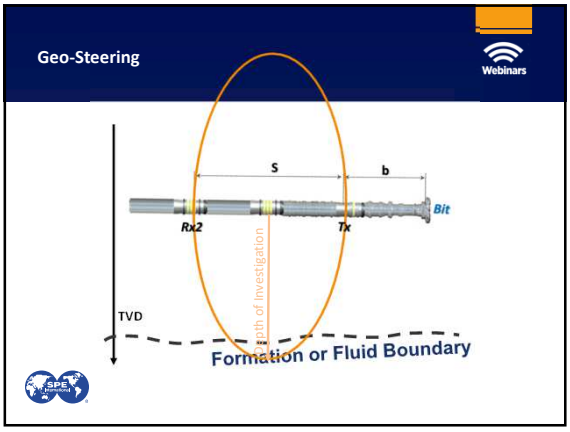


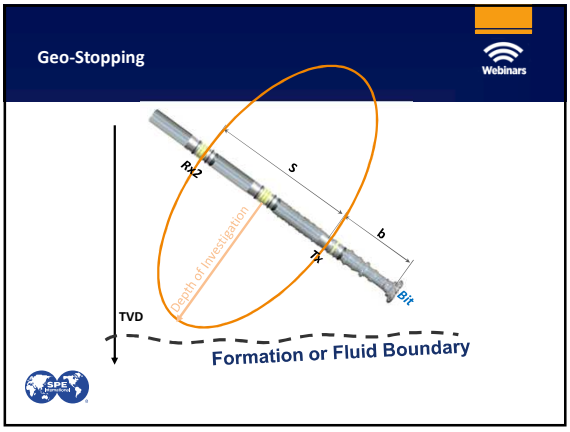
Deep-Directional Resistivity LWD BHA

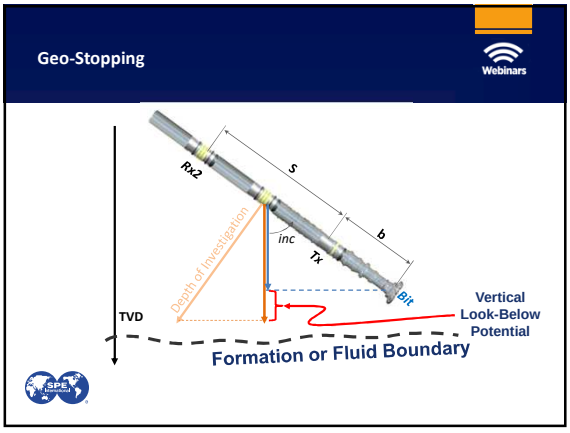


Geo-Steering

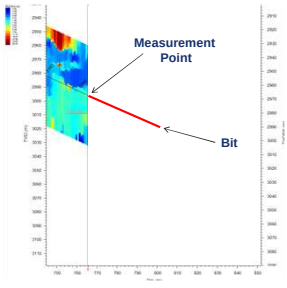



Geo-Steering
Webinars
S
b
Bit
Rx2
Tx
Depth of Investigation
TVD
Formation or Fluid Boundary

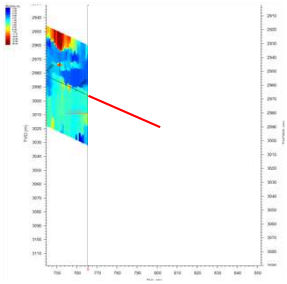

Geo-Stopping
Webinars
Rx2
S
b
Tx
Bit
Depth of Investigation
TVD
Formation or Fluid Boundary


Geo-Stopping
Webinars
Rx2
S
b
inc
Tx
Bit
Depth of Investigation
Vertical
Look-Below
Potential
TVD
Formation or Fluid Boundary

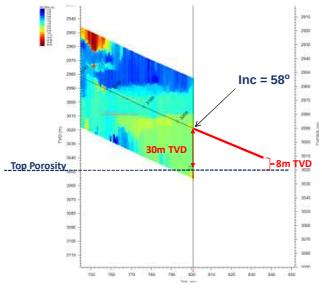
Geo-Stopping Example



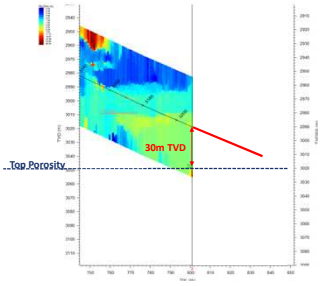
Geo-Stopping Example



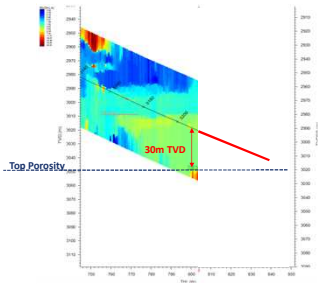
Geo-Stopping Example



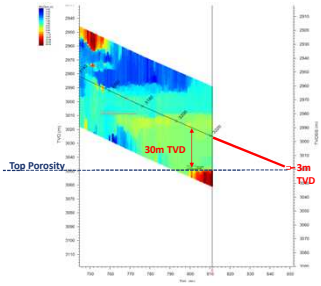
Geo-Stopping Example



Geo-Stopping Example

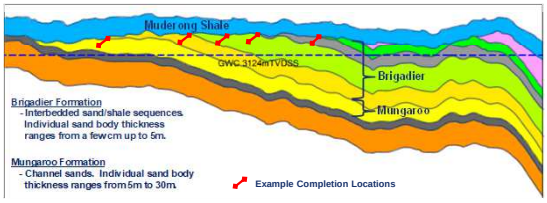


Geo-Stopping Example



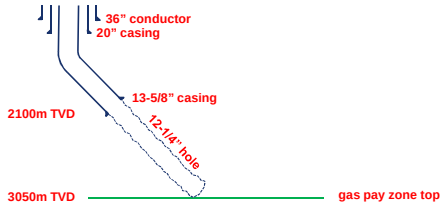
More details on this technique can be found in **SPE-173169-PR**

Wheatstone Geologic Cross-Section

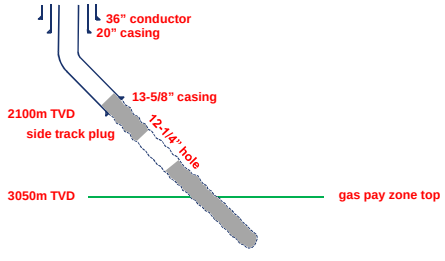


- Brigadier: k_h = 1.5 darcies & k_v/k_h = 0.1
- Mungaroo: k_h = 8 darcies & k_v/k_h = 0.9

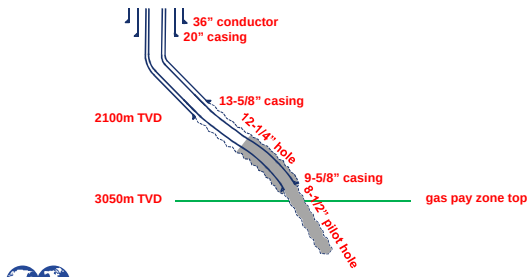
Pilot Hole Execution (original plan)



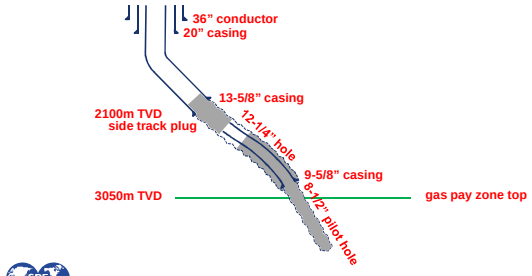
Pilot Hole Execution (original plan)



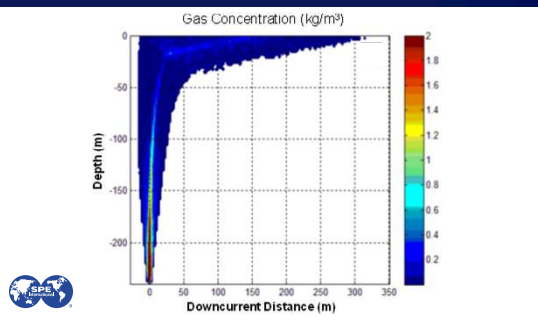
Pilot Hole Execution (final plan)



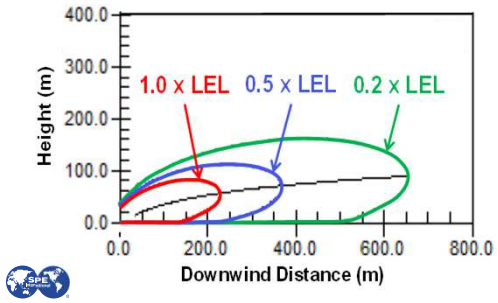
Pilot Hole Execution (final plan)



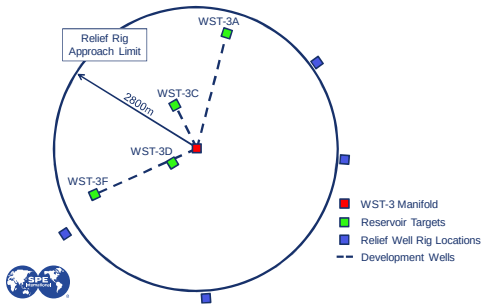
Blowout Gas Plume Modeling (below water line)



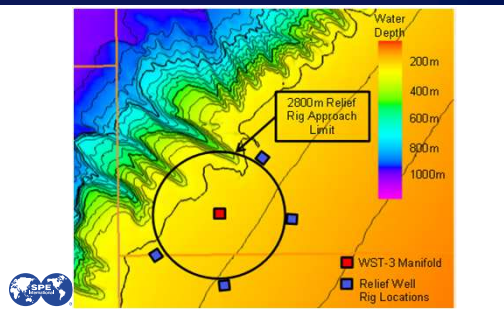
Blowout Gas Plume Modeling (above water line)



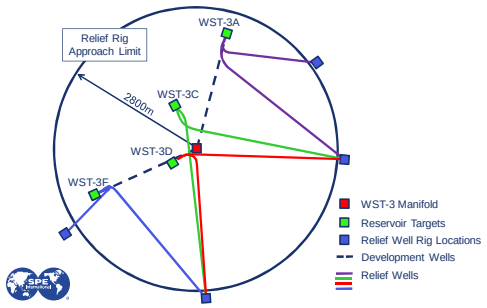
Relief Well Trajectory and Rig Placement Planning



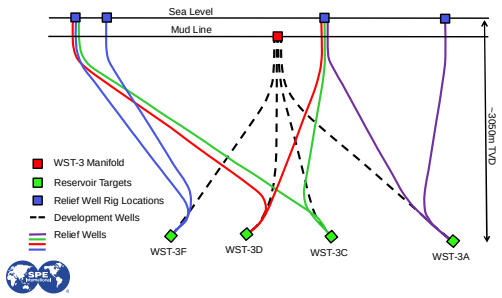
Relief Well Trajectory and Rig Placement Planning



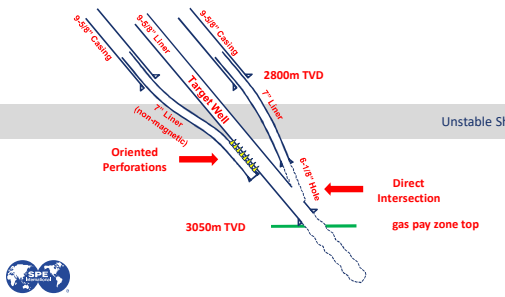
Relief Well Trajectory and Rig Placement Planning



Relief Well Trajectory and Rig Placement Planning

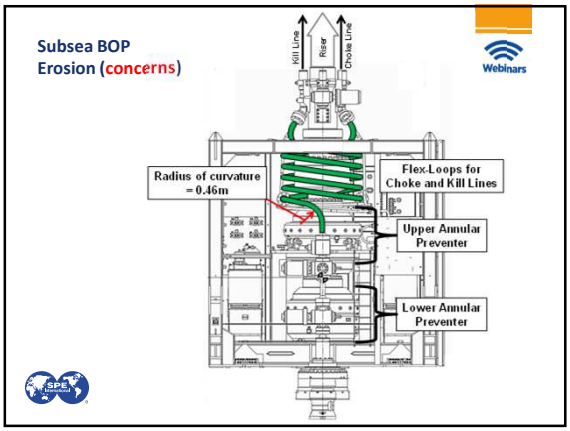


Dual Relief Well Intersection Scenario

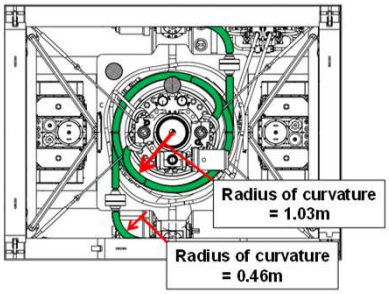


Blowout Well Name (country)	BOP Type	Maximum Reported Pumping Rate (for a single well)	Fluid Density & Type	Total Time Pumping (Solids-Bearing Fluid Only)
Solids-Free Fluid				
Arun C-II-2 [2, 17] (Indonesia)	Surface BOP	126 bpm	8.5 ppg water	---
Cox No. 1 [3] (United States)	Surface BOP	43 bpm	8.5 ppg water	---
El Isba 123 [16, 17] (Syria)	Surface BOP	120 bpm	8.5 ppg water	---
Enchova 19D [15] (Brazil)	Subsea BOP	72 bpm	8.5 ppg water	---
Fateh L-3 [1, 17] (Dubai)	Surface BOP	160 bpm	8.5 ppg water	---
Ixtoc No. 1 [17, 21] (Mexico)	Surface BOP	100 bpm	8.5 ppg water	---
Sheep Mountain 4-15-H [14, 17] (United States)	Surface BOP	64 bpm	8.5 ppg water	---
Sheep Mountain 4-15-H [14, 17] (United States)	Surface BOP	60 bpm	10.5 ppg brine	---
West Cameron 165 No. 3 [13] (United States)	Surface BOP	75 bpm	8.5 ppg water	---

Blowout Well Name (country)	BOP Type	Maximum Reported Pumping Rate (for a single well)	Fluid Density & Type	Total Time Pumping (Solids-Bearing Fluid Only)
Solids-Bearing Fluid				
Fateh L-3 [1, 17] (Dubai)	Surface BOP	115 bpm	18 ppg mud	9 minutes
Fateh L-3 [1, 17] (Dubai)	Surface BOP	156 bpm	14 ppg mud	36 minutes
Fateh L-3 [1, 17] (Dubai)	Surface BOP	190 bpm	11.5 ppg mud	53 minutes
Cox No. 1 [3] (United States)	Surface BOP	57 bpm	18.3 ppg cement	20 minutes
Sheep Mountain 4-15-H [14, 17] (United States)	Surface BOP	31 bpm	15.5 ppg mud	33 minutes
Well 159 [6] (Bahrain)	Surface BOP	10 bpm	11.6 ppg mud	Unknown
Well 159 [6] (Bahrain)	Surface BOP	10 bpm	11.6 ppg cement	10 minutes

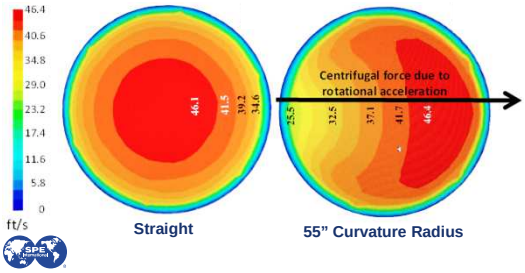


Subsea BOP
Erosion (concerns)



Subsea BOP
Erosion (concerns)

Velocity contours of water in 2.063" ID coiled tubing (10 bpm)



Straight

55" Curvature Radius

Subsea BOP
Erosion (considerations / suggestions)

- The fluid erosion limit of a subsea BOP flex loop is undefined:
  - Nothing in the publicly available industry literature on the topic
  - Results in a lack of understanding concerning the fluid injection capacity of single relief well
- Suggest CFD erosion modeling combined with full-scale erosion testing in the laboratory:
  - Laboratory testing is necessary to calibrate the CFD model

Conclusions

- All nine Wheatstone wells were drilled and cased to within <3m of top of the gas pay without penetrating into it.
- Drilling and completion of the reservoir section occurred without incident.
  - However, a blowout at this phase would still require two relief wells.
- Capping stacks are not an option at Wheatstone due to the shallow water depths (220m):
  - Thus, relief wells are our only method for responding to a blowout

Conclusions

- A better understanding of subsea BOP erosion risk would allow weighted fluid injection limits to be better defined.
  - This would result in a clearer understanding of the number of required relief wells.
    - This could be a message that people don't want to hear – i.e., "You might need more relief wells than you originally thought."

Conclusions

- A unmitigated Wheatstone blowout could have had corporate or society level implications. Hence, guided by our corporate values and culture, we invested significant time and money to…
  1) redesign our well and execution plans so as to minimize the number of required relief wells to 2,
  2) ensure that the details of a 2-relief well response plan were sufficiently understood for all Wheatstone wells and
  3) guarantee that operational mistakes cannot result in a scenario that could require more than 2 relief wells.

Conclusions

- A unmitigated Wheatstone blowout could have had corporate or society level implications. Hence, guided by ~~our corporate~~ values and culture, we invested significant time and money to…
  1) redesign our well and execution plans so as to minimize the number of required relief wells to 2,
  2) ensure that the details of a 2-relief well response plan were sufficiently understood for all Wheatstone wells and
  3) guarantee that operational mistakes cannot result in a scenario that could require more than 2 relief wells.

Corporate Vision:
To be recognized and admired by industry and the communities in which we operate as world-class in safety, health, environment and efficiency.