Propellant Perforation for a Depleted Carbonate Subsea Gas Well – Malampaya

Presenter: Nicholas Hendry,
HPHT Completion Engineer
Shell U.K.
Co-Authors & Acknowledgement

- Jim Gilliat, Baker Hughes
- Mark Brinsden, Shell
- Neil Harvey, Shell
- Vikas Bhushan, Shell
- Milind Bhagwat, Shell
- Michael Tan, Shell
Agenda

- Malampaya Asset - Overview
- Malampaya Phase 2 Project – Overview
- Well Performance: Expected vs. Actual
- STIMGUN Selection
- Process Safety Due Diligence
  - PULSFRAC Modeling
- Conclusions & Project Learning's
1.0

Malampaya Asset

Overview
Malampaya Asset

Malampaya Deep water Gas to Power Project

Reservoir: Deep water, gas carbonate

Wells: 7 subsea wells in 820m water

Flowlines: 2 x 28 km Corrosion Resistant Alloy flowlines

Platform: Concrete gravity base platform in 43m water, offshore dehydration, continuous Methanol (MeOH) injection, remote control from onshore gas plant

Pipeline: 504 km 24” gas export pipeline

Gas plant: Onshore treatment plant uses amine process to sweeten and mole sieves to dehydrate the landed sour gas. Currently operating in dry gas mode (i.e. low H₂S)

Customers: Gas sold to 3 power stations (design 2700 MW)

Capacity: 528 MMscf/d of gas
            32,800 bbl/d of condensate
Subsea to Shallow Water Platform to onshore...

- Gas dehydration
- Gas dehydrating
- Condensate stabilisation
- Export compression
- Depletion compression

Upstream:
- Catenary Anchored Leg Mooring (CALM) buoy for tanker loading of condensate

Downstream:
- Sulphur Recovery
- H2S removal
- Metering
- Supply base

- W820 m
- 4 Additional development wells (2009)

- W3 m
- 3rd flowline (2021)

- W43 m
- Subsea manifold

- 28 km
- 504 km
MALAMPAYA RESERVOIR CHARACTERISTICS

- Carbonate – vugs, karsts, fractures – Highly Heterogeneous
- Average Porosity 18%
- Average Matrix Permeability 250-350 mD/ Effective Permeability 2 D
- Reservoir Temperature 115 deg C
Reservoir Pressure depleted by a third in 10 years

Biggest subsurface challenge – drilling in a highly fractured depleted carbonate
2.0

Malampaya Phase 2 Overview

Status Update
Completion Overview

- Max. Deviation 49.1°
- Design Life 20 years
- Cased & Perforated
- Zero intervention philosophy
- Through tubing perforation
  - 2” CT N₂ for unloading if required
- Stimulation: STIMGUN
- Tubing: 7” X 9-5/8” X 7”
  - TR-SCSSSV 7”
- Surveillance: Permanent Downhole Pressure Gauge (PDHG)
Completion schematic

- 7” 29# SM13Cr S110 VAM TOP HC Tubing
- 7” TRSSSV
- 9 5/8” 53.5# SM13Cr S110 VAM 21 Tubing
- 7” 29# SM13Cr S110 VAM TOP HC Tubing
- 7” PDHG Mandrel
- 9 5/8” Hydrostatic Set Production Packer
- AOF nipple
- Guide bottom
Gun Selection

- 200 m of perforation length per well
- 7” Liner Cased & Perforated Completion
- 3-3/8” OD STIMGUN was shortlisted
  - Min ID of Tubing hanger at subsea tree was 5.12”
- Standard 6 SPF shot density, 60 deg phasing
- Deep Penetrating HMX charges
3.0
Well Performance: Expected vs Actual

Overview
Drilled reservoir section with total losses indicating a highly fractured carbonate as expected. Fractures observed on Image logs.

- Reservoir quality more heterogeneous than the nearest offset well
- High permeability zones observed from log data.
- Perforation interval optimized by lowering 5 m to connect to deeper high permeability zones.
Well Testing Overview

- Estimated 150 MMscf/day demonstrated
- Clean up criteria achieved
- Final Salinity 235 ppm and 0% BSW solids
- ~200 ft flare – Weather favourable
- Dual Separator mode on the rig flowed to 120 MMscf/day (measured) - STABLE flow
Expected IPR vs. Actual Flow Performance

Benefit of near well bore stimulation & thick high permeability reservoir sections
4.0

STIMGUN Selection
Why did we need some form of Stimulation?

- Reservoir Pressure depleted by 1/3rd from virgin pressure
- Huge drilling & cementing losses expected
- Presence of Karsts
- Could expect thick damage zone around the wellbore that could go beyond depth of penetration offered by conventional perforations
- Large uncertainty in permeability prognosis – Carbonates
- Inefficient clean-up due to insufficient delta P or deeper invasion in high permeability zones leading to a turbulent drainage pattern into the wellbore
- Zero Intervention Philosophy - Well Completion Design
  - No interventions preferred. Stimulation(acid jobs) in retrospect if wells do not flow at expected capacity
- Insurance against non-deliverability of wells due to formation damage
  - Contributes to 40% of the Philippines Luzon Island’s power grid
What we needed?

- Some near wellbore stimulation to bypass any potential damage zone
- Not expecting new fracture generation as the reservoir was already fractured
- Propellant loading could be kept modest to achieve this objective
Acid Jobs vs. Propellant Assisted Perforation

- Complete stimulation of the reservoir section is very difficult to achieve using acid diversion techniques in a karstic environment due to the large variability in the permeability.

- Technology Solution: Propellant-assisted perforating technique - Stimulation with Perforation – STIMGUN

- Propellant-assisted perforating was considered as it achieves effective stimulation diversion equally across the entire perforated interval.

- Additionally, its usage eliminates the need for conventional, separate acid stimulation saving rig time and costs while reducing HS&E risks.
5.0

PROCESS SAFETY DUE DILLIGENCE

PULSFRAC Modeling
Biggest Uncertainty

- Quality of cement behind the 7” liner

![Image of cement in rock]

*Figure 2 – Gas expansion of the burning propellant sleeve as the formation is fractured.*

- Model the Worst Case Scenario: Assume complete loss of cement to the depleted reservoir

![Image of depleted reservoir]
PULSFRAC Modeling Results

- StimGun is loaded at 30% coverage, burn is complete.
- There is no fracturing but a surge effect has reduced the initial skin from +4.2 to zero.
PULSFRAC Modeling Results

- Lack of reservoir pressure means no fracturing.
- There is no “push back” from the formation, therefore pressure does not build up in the wellbore.
- 30% coverage does not provide enough energy to promote fracturing.
- This is a result of the formation pressure allowing the gas to feed into the reservoir rather than building up in the wellbore.
Conclusions

- Stimulation was deemed necessary for Malampaya wells given the depleted reservoir and total losses scenario expected.
- STIMGUN was selected based on optimization of rig time, ineffectiveness of acid jobs in a karstified, fractured carbonate and Process Safety considerations.
- 2” CT collapse risk mitigation achieved by:
  - Moderate propellant loading to 30%
  - Overbalance Perforation preferred to make system stiffer
  - Seawater + MEG mixture inside and outside coil (for hydrate prevention)
  - N2 lift contingency as well unloading plan if required
- 200 m Perforation guns perforated successfully with 30% propellant loading
- Better inflow performance than expected: Benefit of near well bore stimulation & thick high permeability reservoir sections
Malampaya Perforation Design - Project Learnings

- Always work very closely with vendor and do not assume
- Get Principal Technical Expert/Subject Matter Expert steer early into the Project to ensure all risks are completely assessed
- Static conditions modeling is not adequate – CIRCA, Cerebrus models
- Detailed dynamic analysis of actual Bottom Hole Assembly (Perforation) should be modeled including the accurate spacer lengths, blank section to assess the impact of pressure surges/dynamic UB
- PULSFRAC Modeling: Always update the models after drilling the reservoir section with actual LWD based reservoir quality info to see how the dynamic perforation wave impacts the bottom hole assembly and completion components and how much energy gets absorbed by the formation
Malampaya Perforation Design - Project Learnings

- Check for differential pressures across packer and liner hanger components
- 12.8m spacer sub chosen for Malampaya Phase 2 wells to ensure top shot below the rotary for personnel safety while RIH
- Ensure proper Management Of Change is followed and take vendors along in all the discussions
- Time consuming finite element modeling work in PULSFRAC
- As a single operated asset in the Philippines, the operator Shell effectively leveraged on its global resources & expertise, e.g. global technology centers in India, Europe and US, and operations teams in the region. A degree of collaborative virtual working is essential for success in today’s world.