Application of HSPs to the Kraken Field

SPE EuALF

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Adam Downie

Outline

- Kraken overview
- Why HSPs were selected
- Hydraulic design and completion interface
- First Oil
- Pump performance – prediction vs reality
- Flow Assurance and temperature management
- Reliability
- Conclusions

Introduction

Located in Block 9/2b

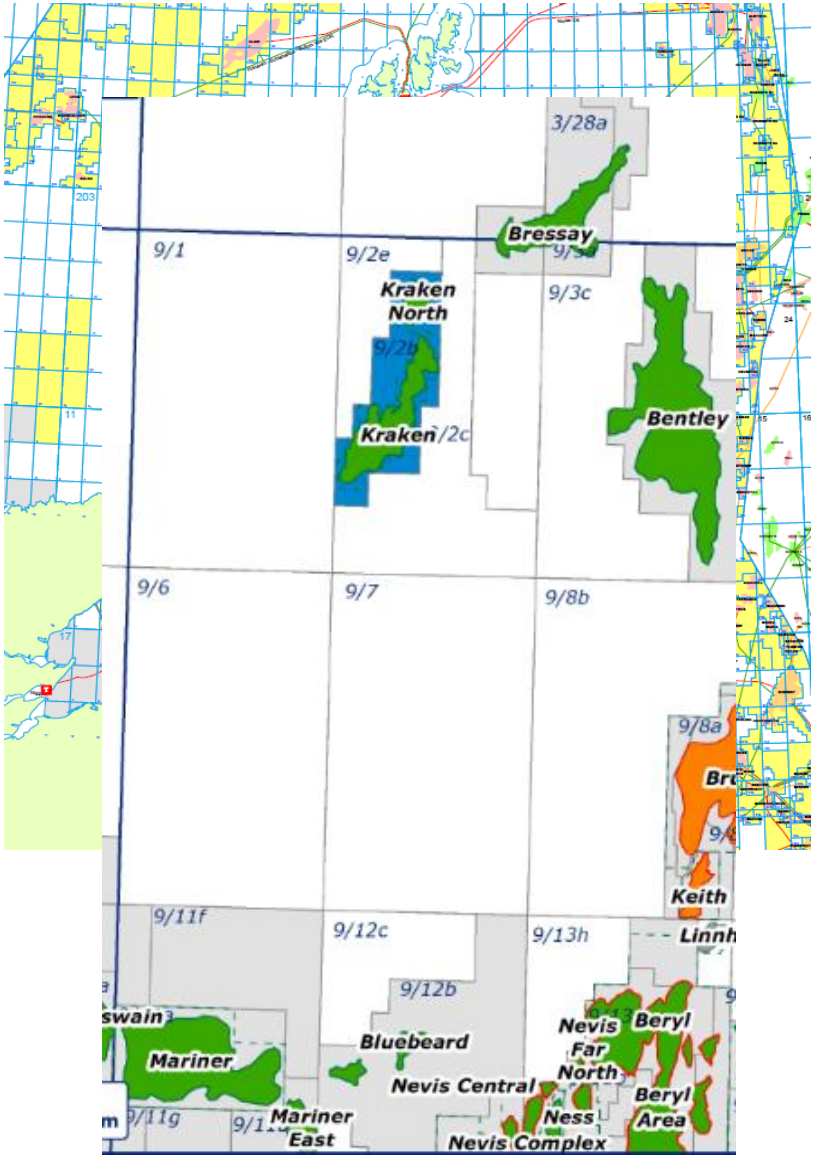
- 350 km NE of Aberdeen
- Discovered 1985
- Licensees: EnQuest, Cairn Energy

Adjacent Heavy Oil Developments

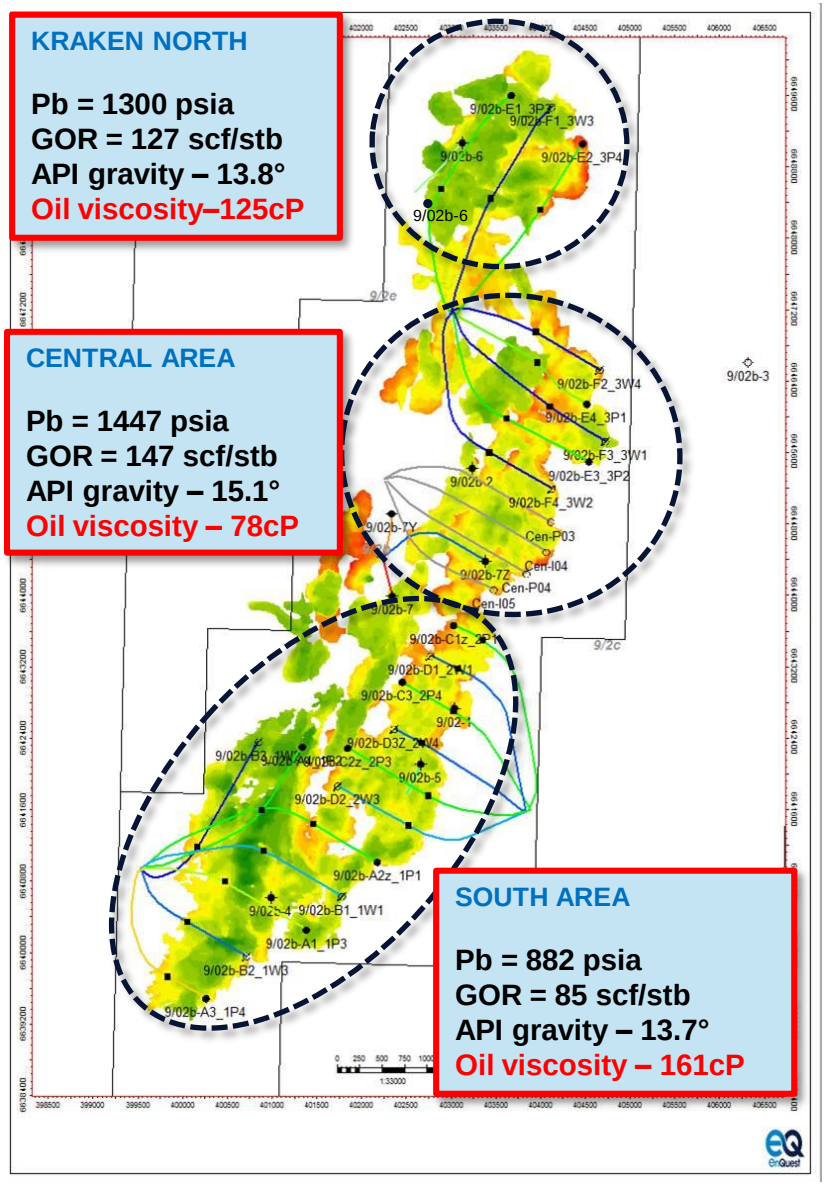
- Bentley (Xcite)
- Bressay (Statoil)
- Mariner (Statoil) – 9/11a

Closest Field Analogue

- Mariner (Heimdal reservoir)



Reservoir & PVT



Rock Quality

- High porosity (~35%)
- High permeability (3-8 Darcies)
- Unconsolidated

Formation

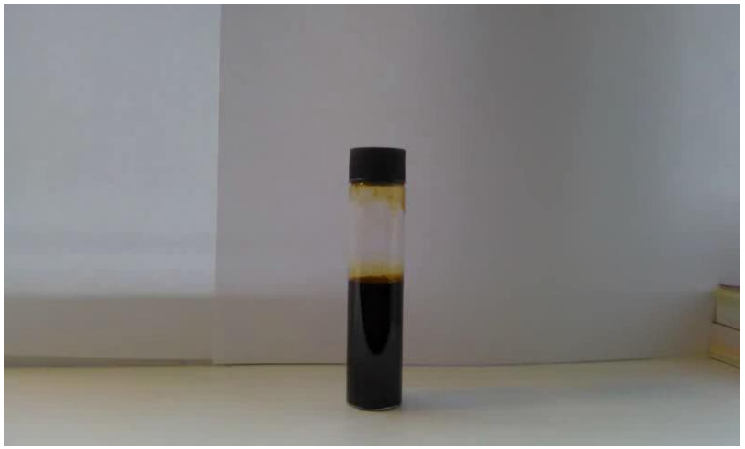
- Heimdal sands (Palaeocene)
- 11 km x 1.5 km
- Sand thickness (40-100’, average 60’)
- No underlying aquifer (underlain by shale)
- No gas caps
- Net:Gross average 90%
- Low reservoir pressure (1742 psia)
- Shallow (3900 ft TVD-SS)
- Cool (108°F)

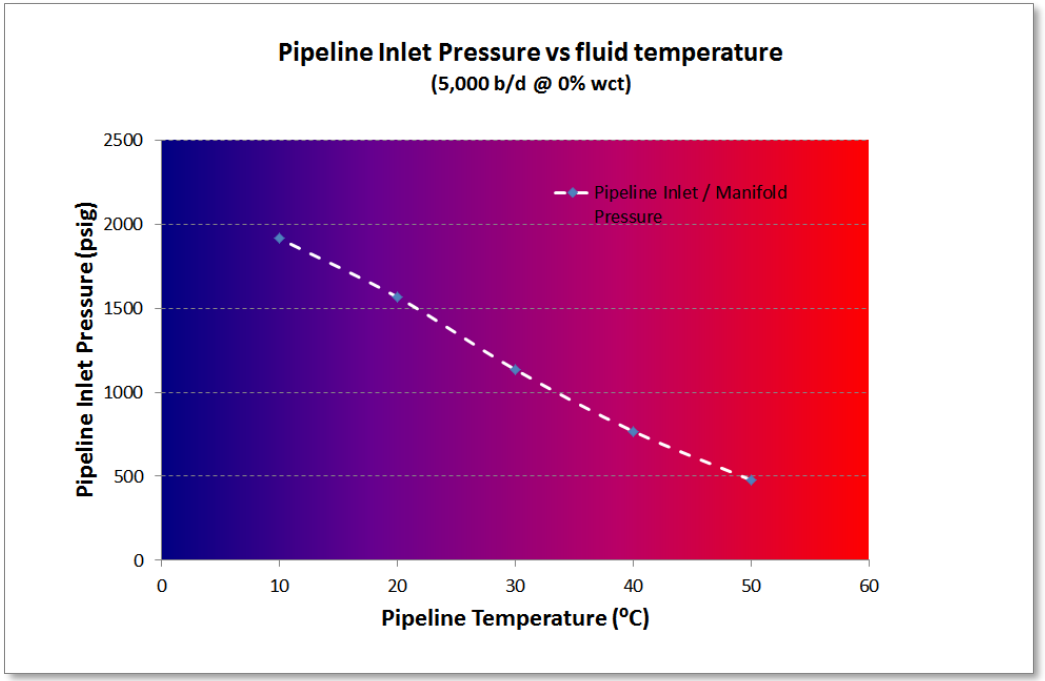
Fluids – 3 PVT regions

Effect of temperature on oil viscosity

T_{RES} : 42ºC

T_{seabed} : 5ºC



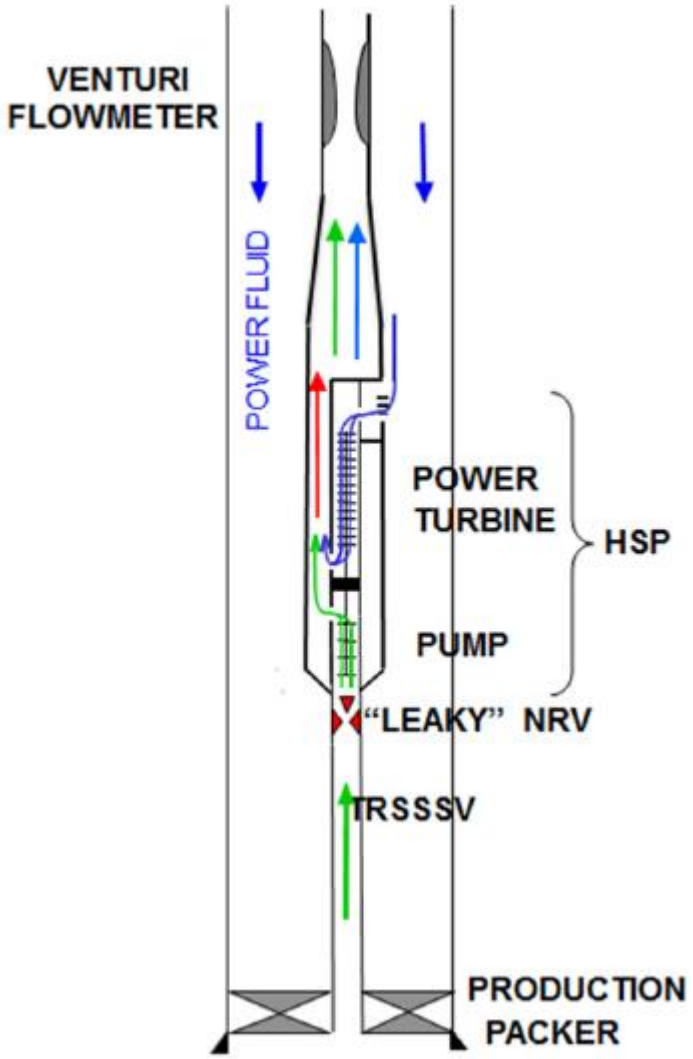


Conclusion: need to retain heat in the system.

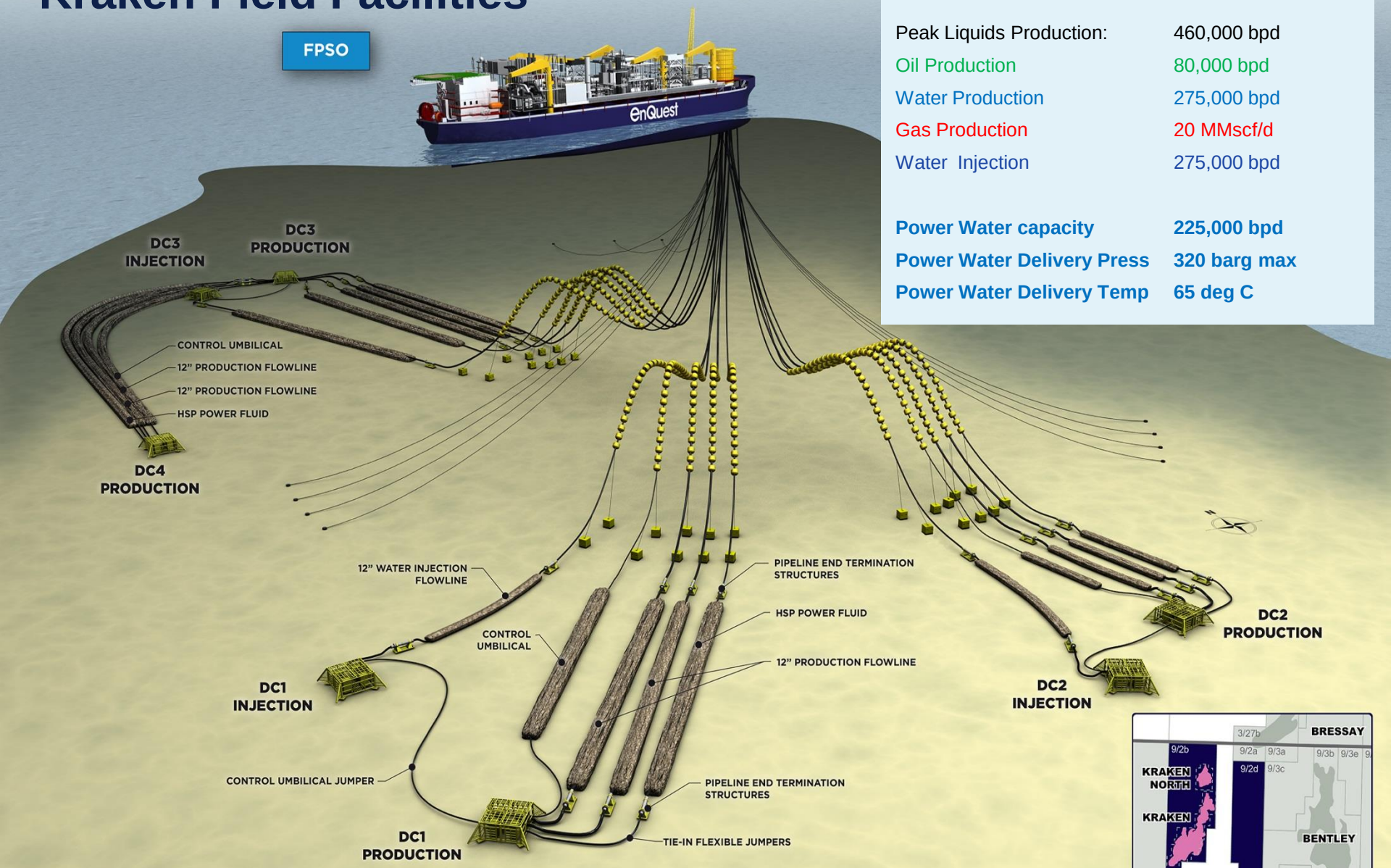
Why were HSPs selected for Kraken?

- Project economics favoured a subsea / FPSO development
- Highly robust, with proven reliability record in an analogue application
- By using heated power water, can provide heat input and ensure a water-continuous flow regime downstream - mitigates effects of high oil viscosity in tubing, pipelines & separators
- Delivers the high levels of head and flow required for economic recovery in the Kraken field
- Can also operate over a very wide range of head / flow conditions within a single pump design – essential for subsea

HSP Principles of Operation



Kraken Field Facilities



Kraken Armada Design Capacities

Peak Liquids Production:	460,000 bpd
Oil Production	80,000 bpd
Water Production	275,000 bpd
Gas Production	20 MMscf/d
Water Injection	275,000 bpd
Power Water capacity	**225,000 bpd**
Power Water Delivery Press	**320 barg max**
Power Water Delivery Temp	**65 deg C**

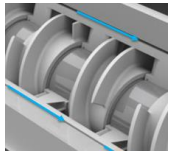
KRAKEN DEVELOPMENT - BLOCK 9/2b

Hydraulic Design

- Supplier selected a pump/turbine combination to maximise production within following design constraints / targets:

Power Water Supply	
Power Water Pressure	Power Water Rate (per well)
320 barg	15,000 bwpd
Reservoir / Completion	
Min FBHP	Maximum Reservoir Flow Rate
Pb-200 psi	20,000 stb/d

- Significantly higher head and power requirements than for earlier application
  - Finalised pump design > **24 x TP145AH stages**



  - Finalised turbine design > **17 x T60C stages**

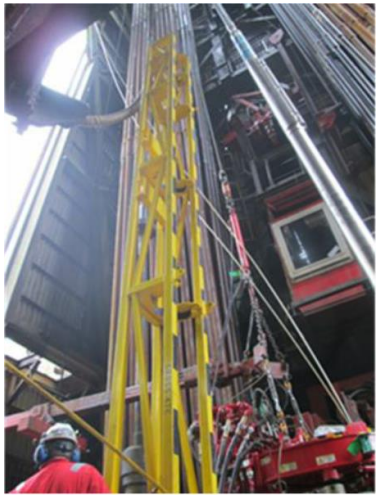
Larger OD T60C turbine blade and increased power fluid rate allows higher hydraulic horsepower to be generated within the power water pressure constraint.

Completion Packaging Issues

- Absence of free gas cap obviated the need for a larger diameter “free-flow” bypass string used previously
- 10¾” casing enabled significant savings in drilling and casing costs
- However, concern about potential for microbially induced corrosion (MIC) led to selection of heavy wall casing (65.7ppf)
- Challenge for supplier to slim down the HSP flow collector and accommodate speed probe
- Resulted in material upgrade to Inconel for all casings & changes in speed probe design to recess the probe as far as possible into the flow collector
- Still a tight fit…

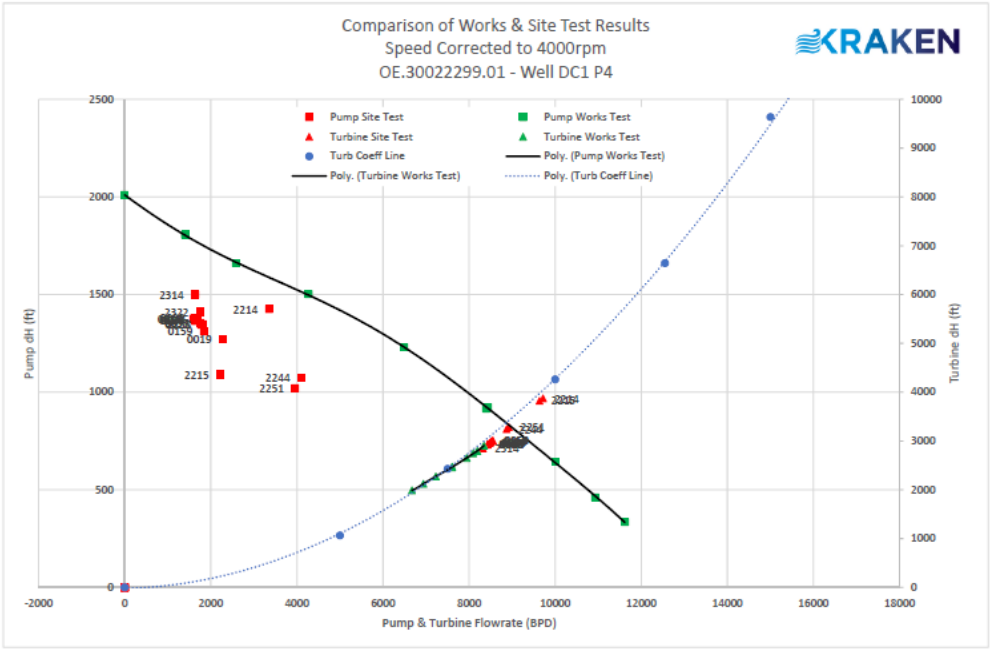
Yard tests to confirm HSP assembly tolerance to dog-legs

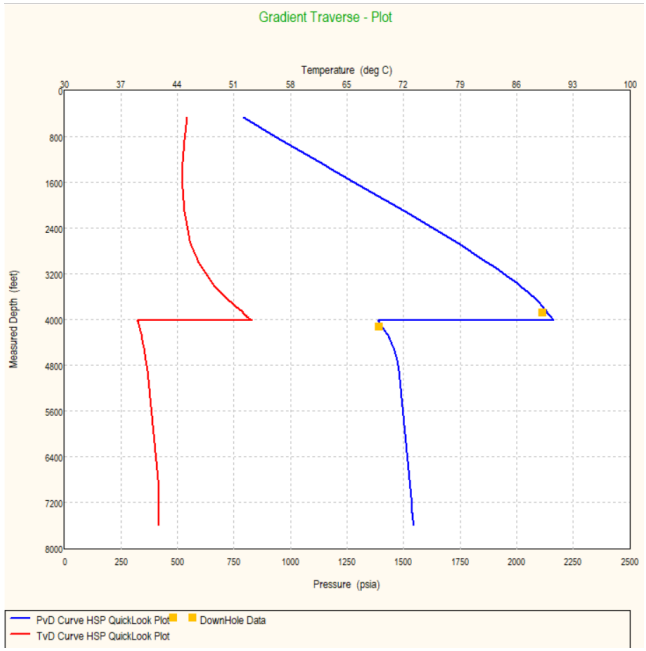
Completion Design



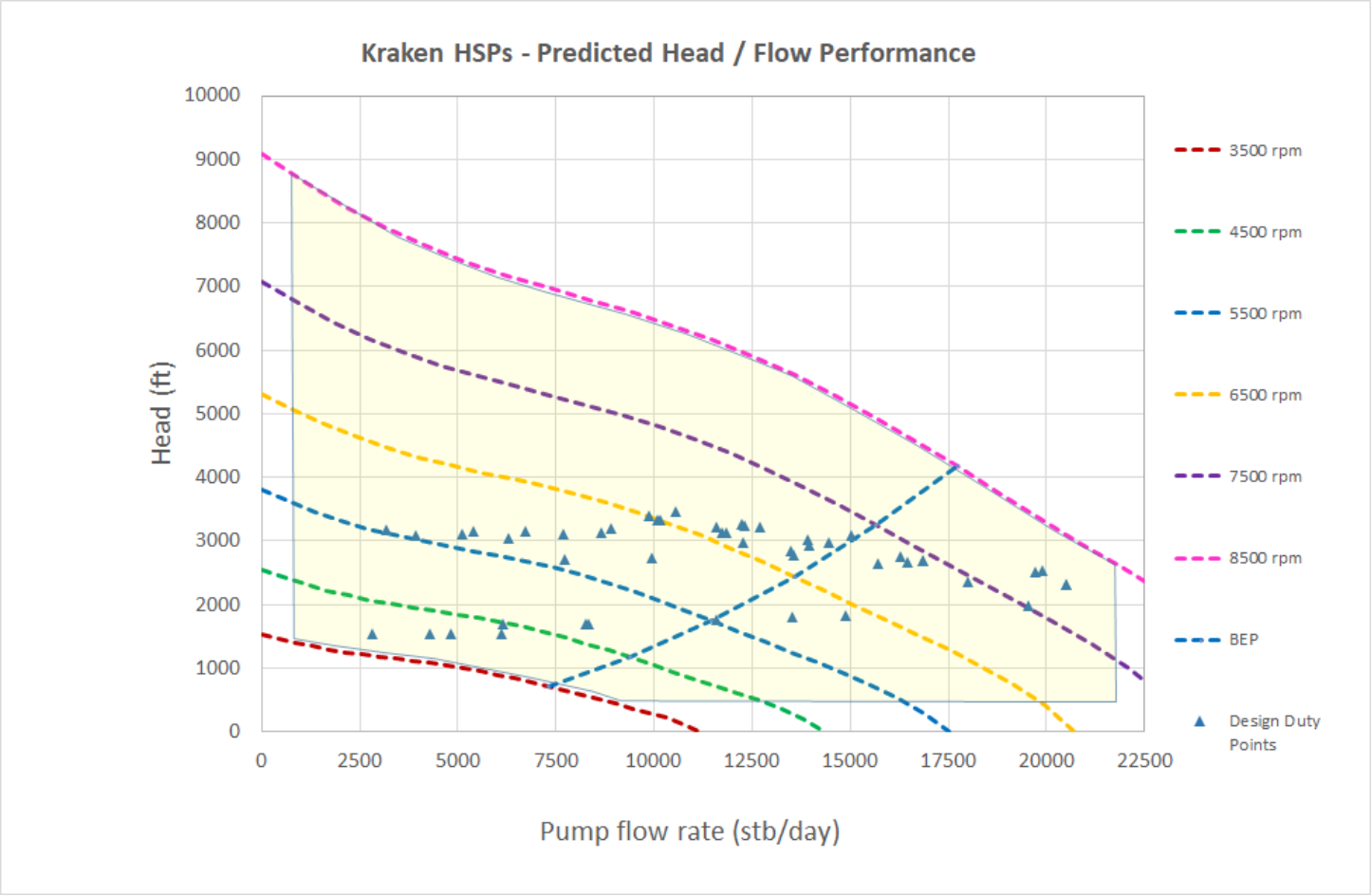
First Oil – small hours 23rd June 2017…..

- DC1 P4 well in South area selected for First Oil
- Pipeline pre-warmed by flowing power fluid across the tree, routed to Test Separator
- Tree XOV valve closed to start HSP rotating and commence clean-up
- Production rate ramped up gradually in accordance with procedure.
- Initial production uneventful, pump and turbine performing close to prediction:



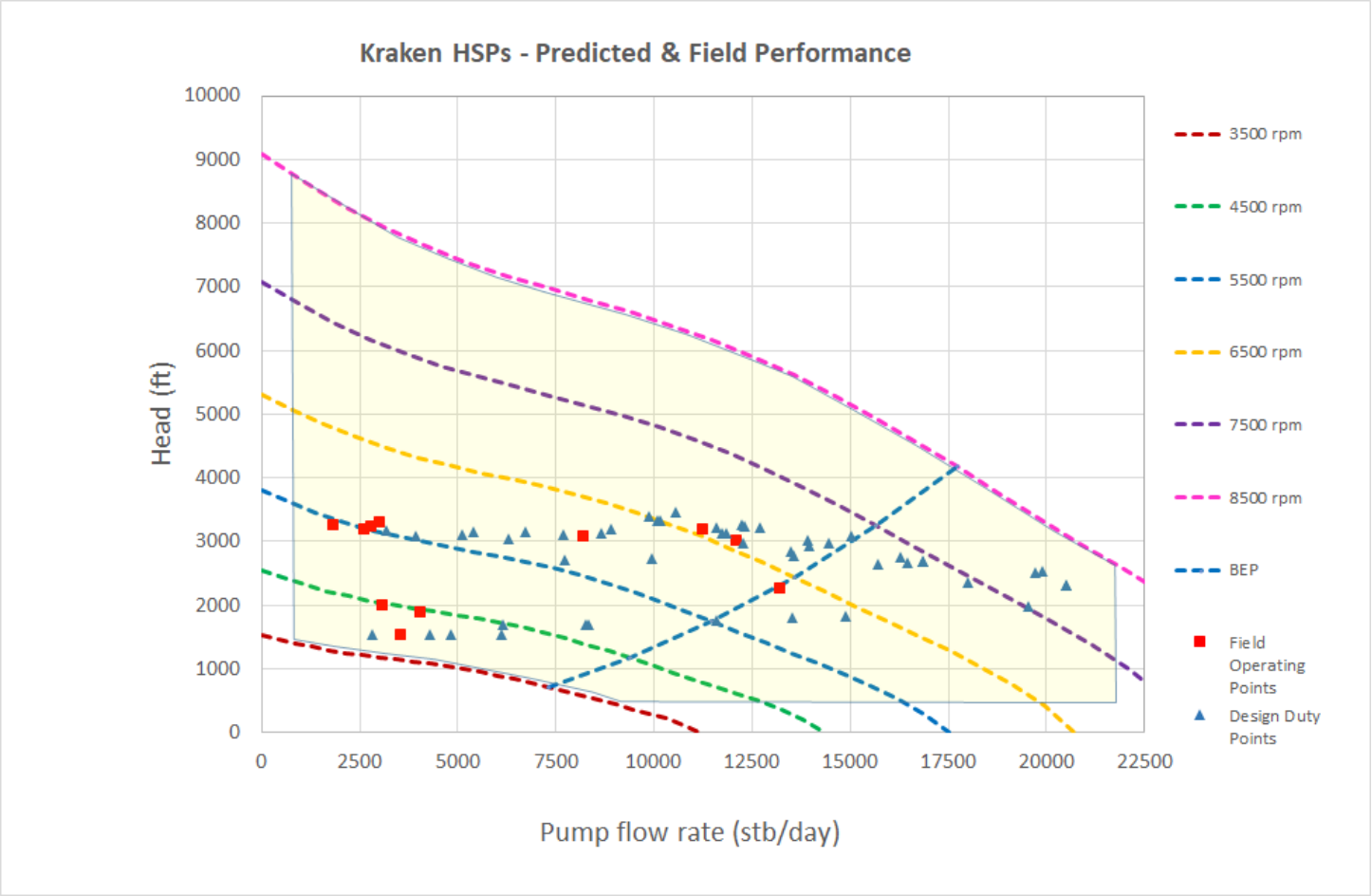


Comparison between design and reality



- Wide range of operating cases modelled to cater for expected + potential inflow conditions
- Illustrates versatility of single pump design

Comparison between design and reality

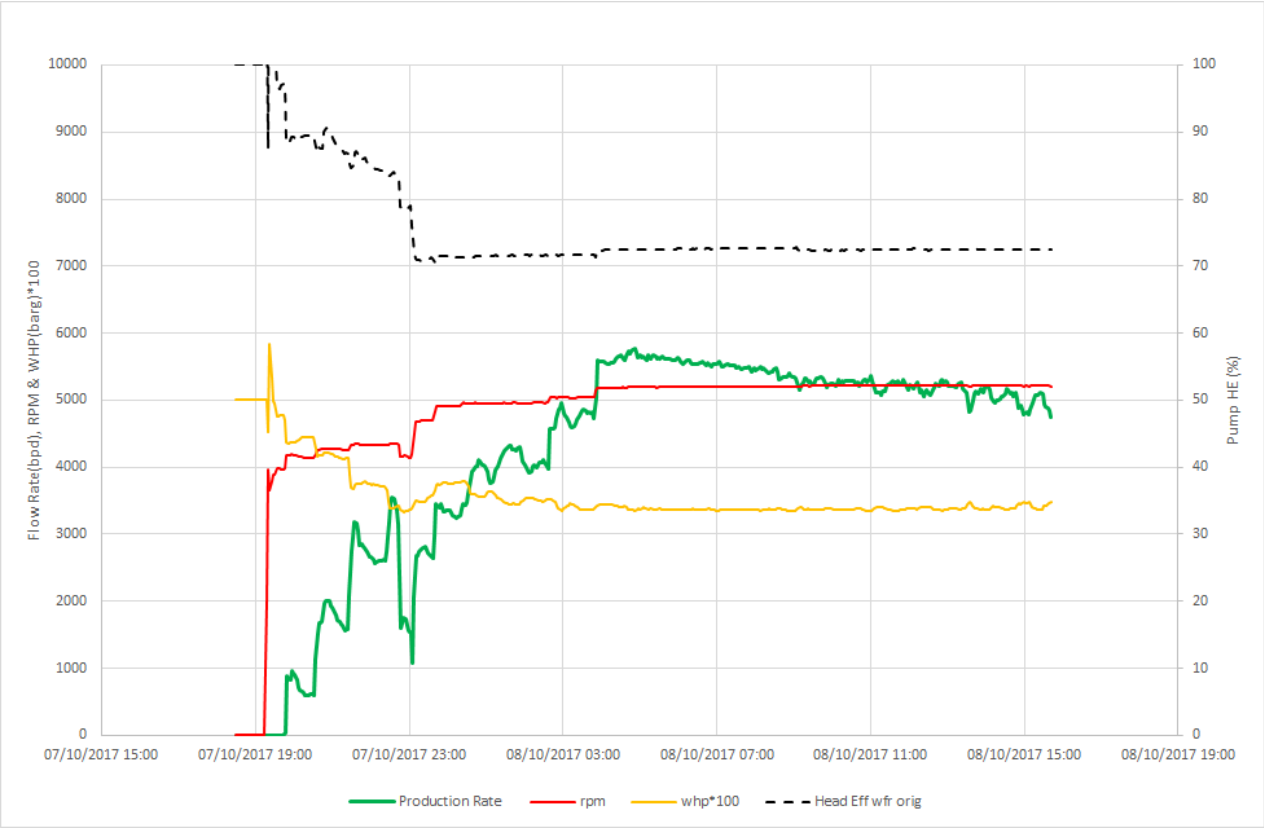


- Field data confirms ability of pumps to meet head and flow requirements
- No well has yet been pump-constrained – a key design objective

Effects of oil and water on pump performance

On start-up of certain wells transition from “wet” to “dry” pump performance observed in downhole data:

- Pump head efficiency drops abruptly, coincident with drop in flow rate
- Transient behaviour immediately on restart due to gravity segregation of power fluid and oil when shut-in



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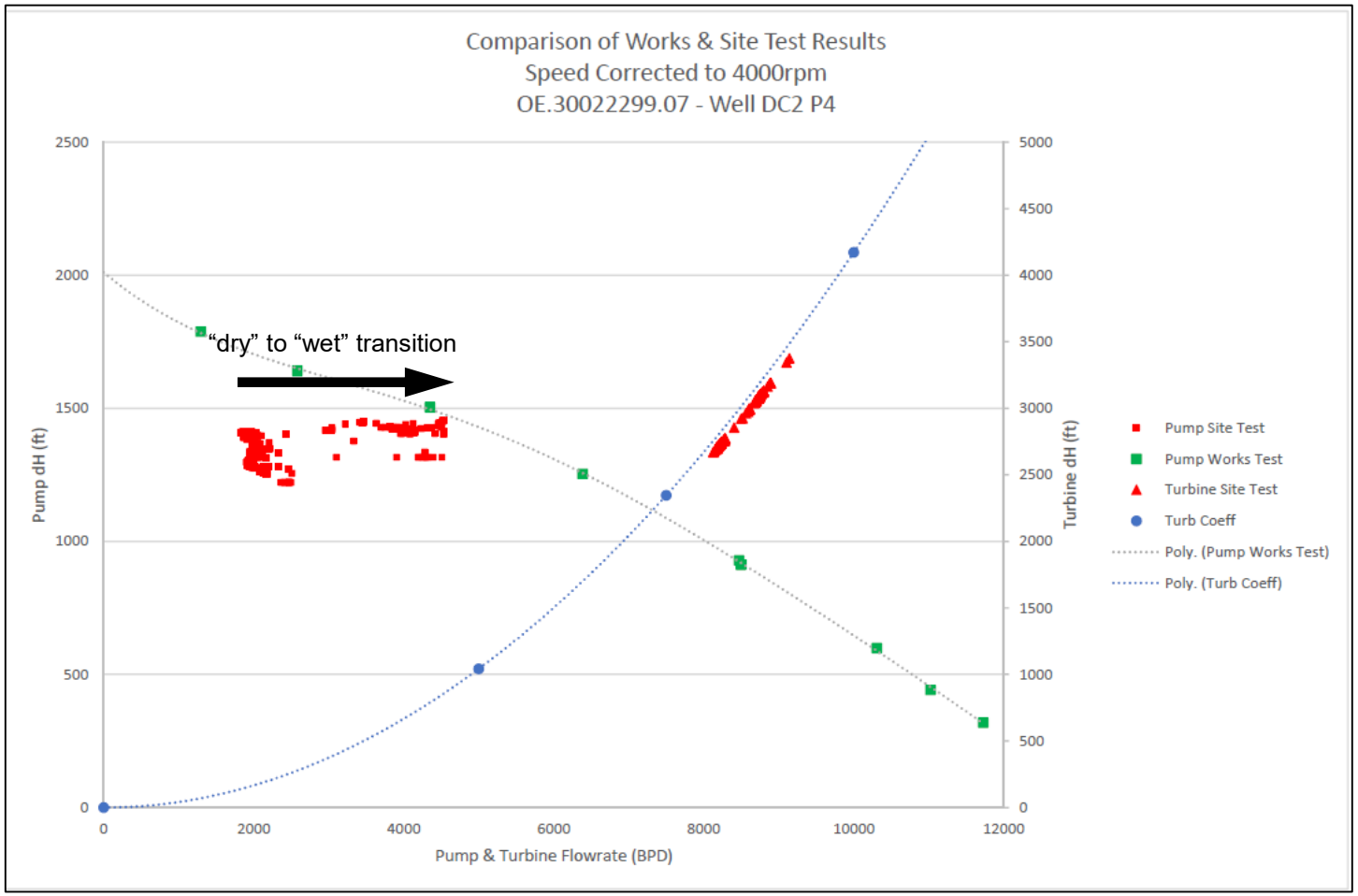
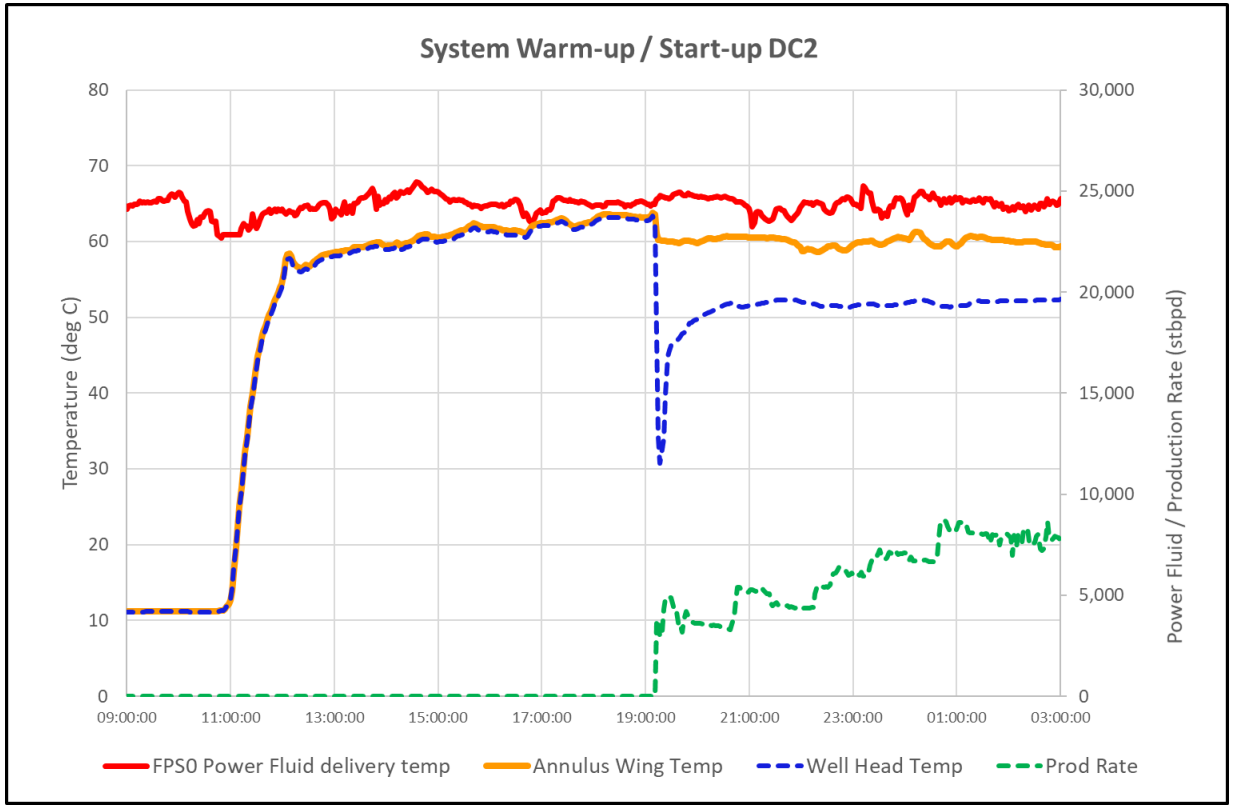


Illustrates how pump performance can transition from "oil" to "water" performance and back again rapidly as a water slug passes through the pump.

Flow Assurance & Temperature Management

- Ability to “round trip” heated power water from the FPSO to the wellheads via the XOV valves has proven very useful for system warm-ups:
  - 8 hours to resume production from cold-start / 1 hour for warm start-up.
  - No requirement for hot oil / diluent circulation or electrical heating



- First stage separation efficiency enhanced by increasing power water temperature

Reliability & Operability

- 11 units now in operation, 2 more producers to be completed during Q4 2018 to Q1 2019
- Collectively units have achieved over 6 pump-years of operation
- Wells all operating at target flowing bottom-hole pressures
- No operational downtime attributable to the downhole pumps
- Downhole monitoring systems all working reliably, providing invaluable data for production optimisation
- Variable speed control of topsides power water pumps is enhancing system operability and minimising well-to-well interactions

Conclusions

- HSPs have been very successfully deployed on Kraken, achieving design basis performance objectives. Reliability 100% almost one year after 1st oil.
- Very broad operating envelope of the HSP has been key in achieving the performance goals.
- Close collaboration between HSP supplier and EnQuest at all stages of the project has been vital to the success of the project.
- Practicality of installing HSPs in a smaller casing size has been demonstrated
- Kraken has re-confirmed the suitability of HSPs for applications where fluids are “difficult” and/or reliability is paramount – a compelling combination of strengths.

Acknowledgements

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