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Completion and Production Challenges in Offshore Heavy Oil – Lessons Learnt from Peregrino

Luiz Fernando Pastre – Completion Engineer

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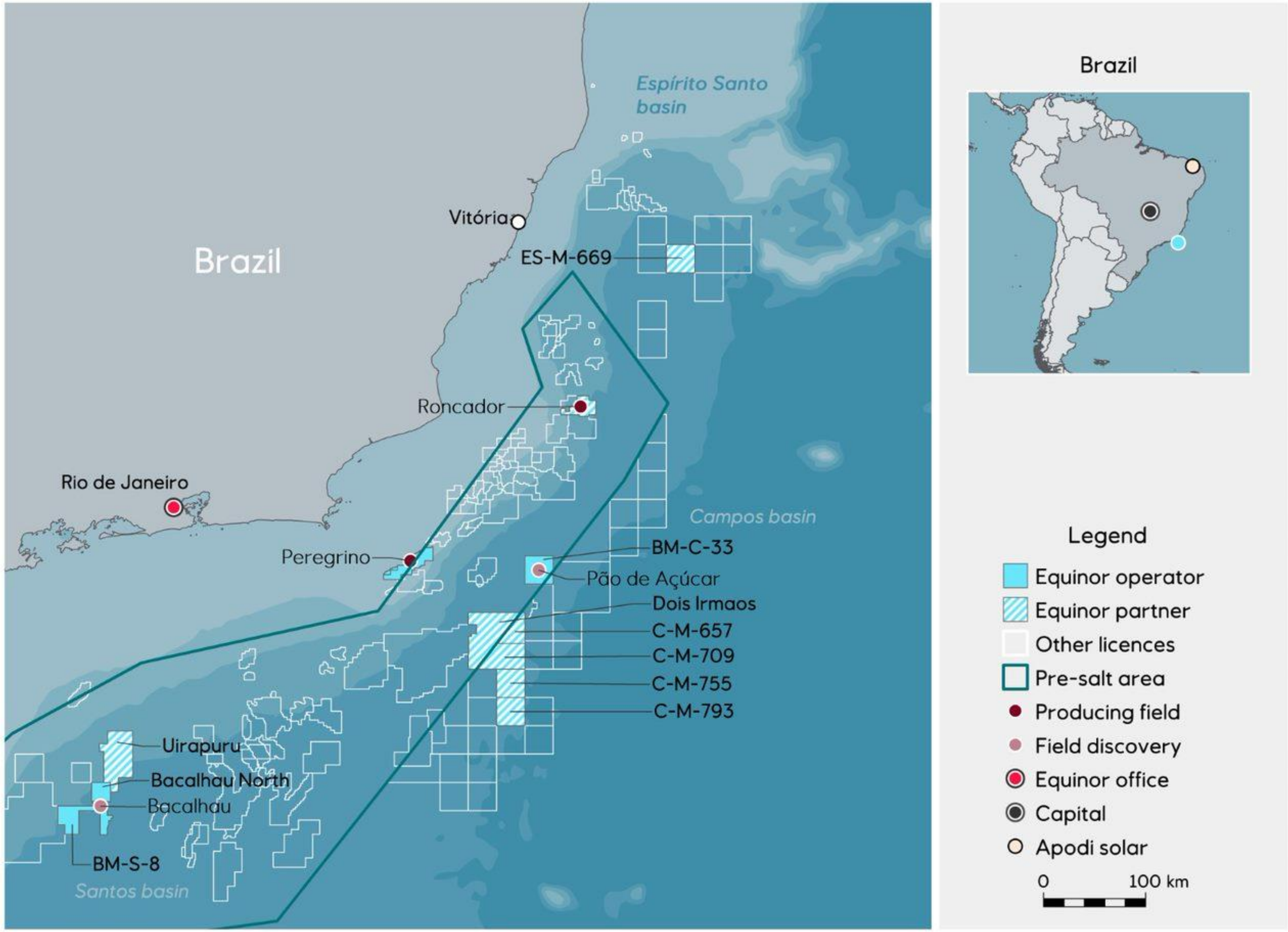
Peregrino Field | Brief History

- Block BM-C-7 in Campos Basin – 85 Km offshore Brazilian coast.
- Discovered in 1994.
- Estimated reserves of 400 million barrels of recoverable oil.
- Heavy oil reservoir (13 deg API).
- Oil viscosity: 390 cP.
- Equinor became field operator in 2008.
- Exploration license for adjacent block BM-C-47 acquired in 2008.
- New block added 273 millions barrels in recoverable reserves.



Open

11 February 2021

Peregrino Field | Field Development

- Field structure consists of 2 drilling capable platforms and 1 FPSO.
- Oil production started in 2011 using ESPs as artificial lift method.
- Current field production is 60-80k barrels of oil a day.
- Over 200 million barrels of oil already produced.
- Third fixed platform under commission for phase II development.
- Largest field operated by Equinor outside Norwegian continental shelf.

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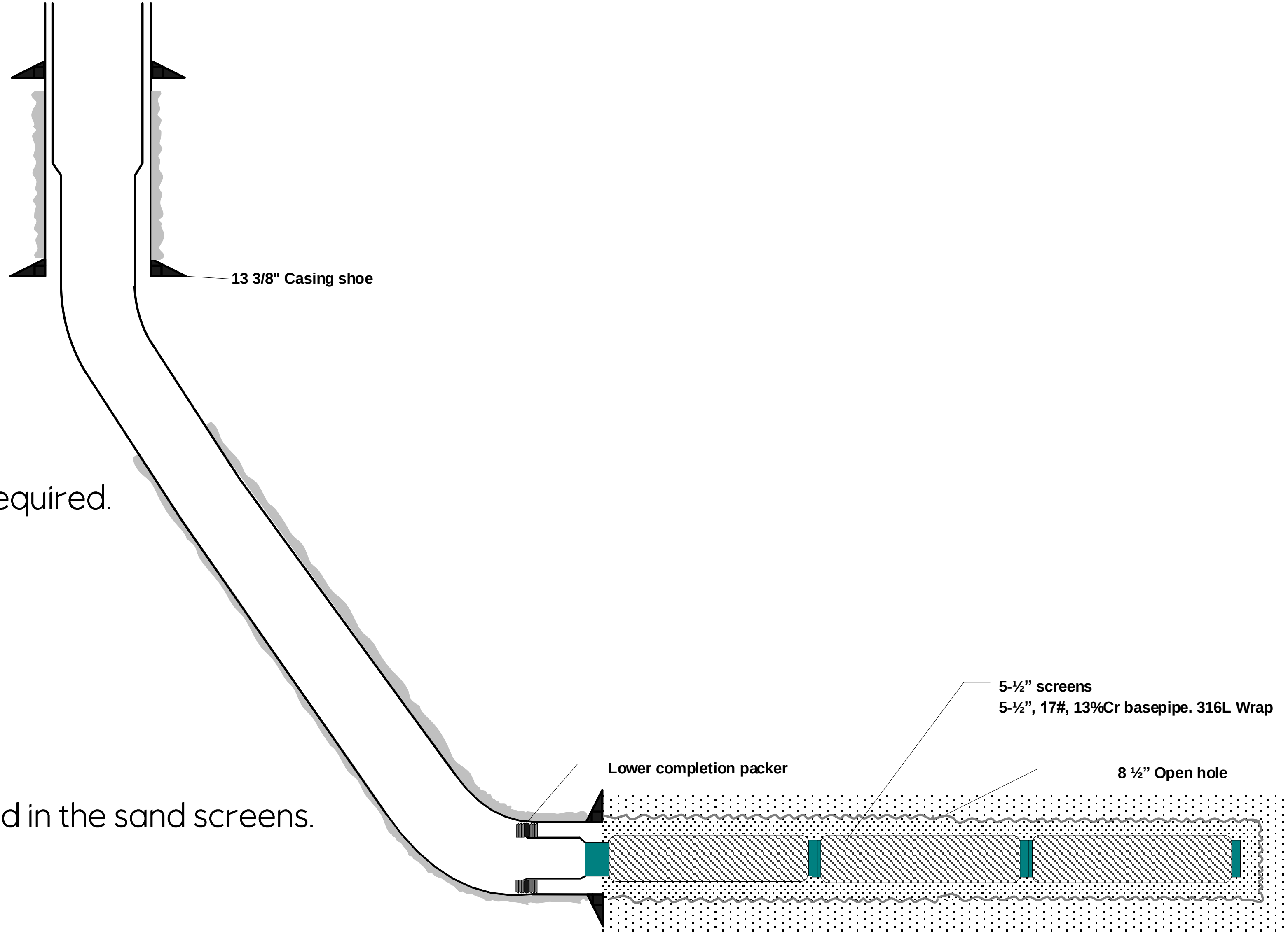
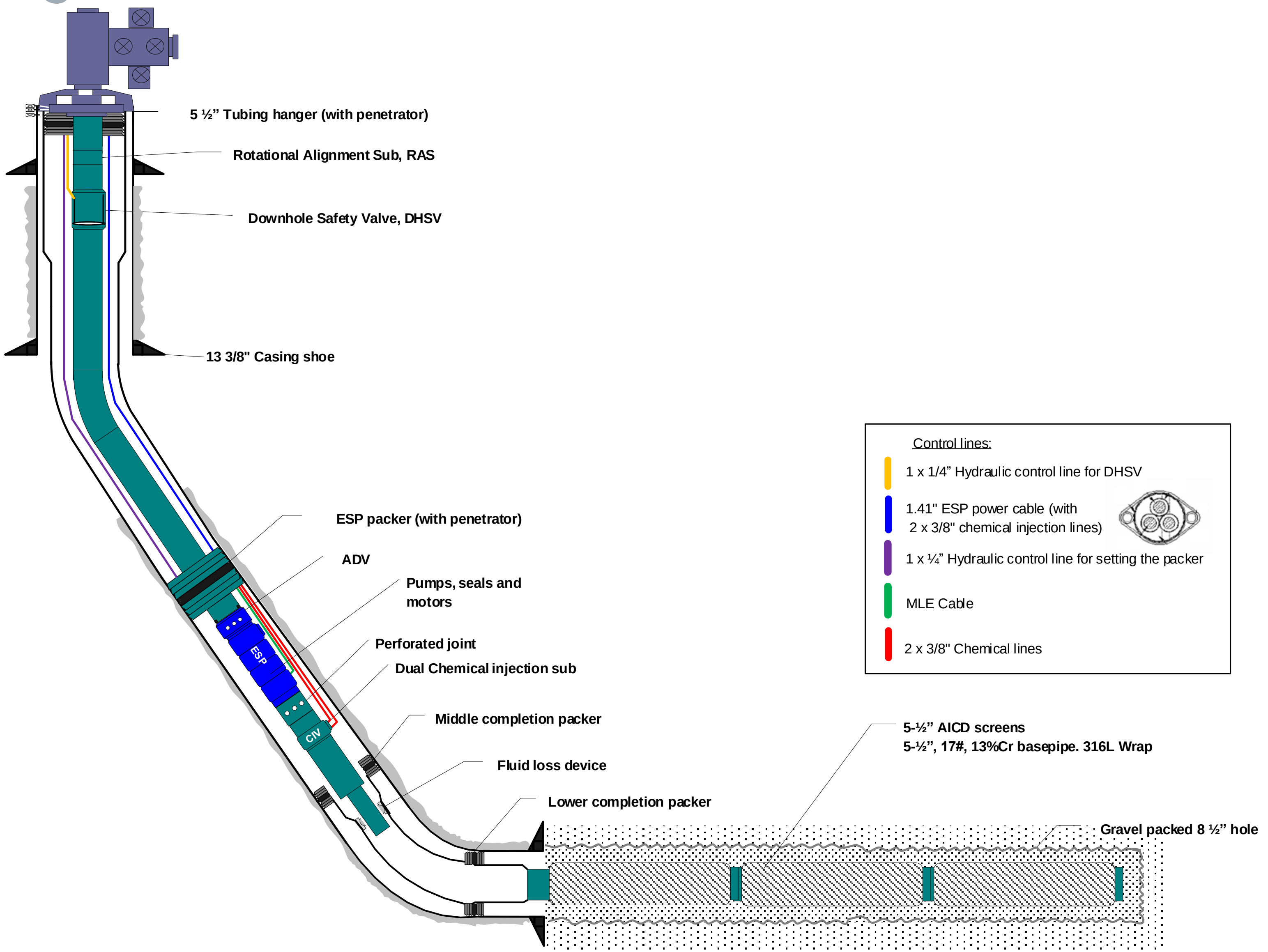
Peregrino Field | Well Design

- **Well Design**
  - Long horizontal sections - up to 7,200 ft.
  - Extended reach wells – up to 28,600 ft.
- **Lower Completion Design**
  - Sand screens deployed in every well.
    - ✓ Detailed torque and drag analysis required.
    - ✓ Landing string selection.
    - ✓ Swivel device.
  - Open Hole Gravel Pack design.
  - Autonomous Inflow Control Devices installed in the sand screens.
    - ✓ Very light weight proppant.



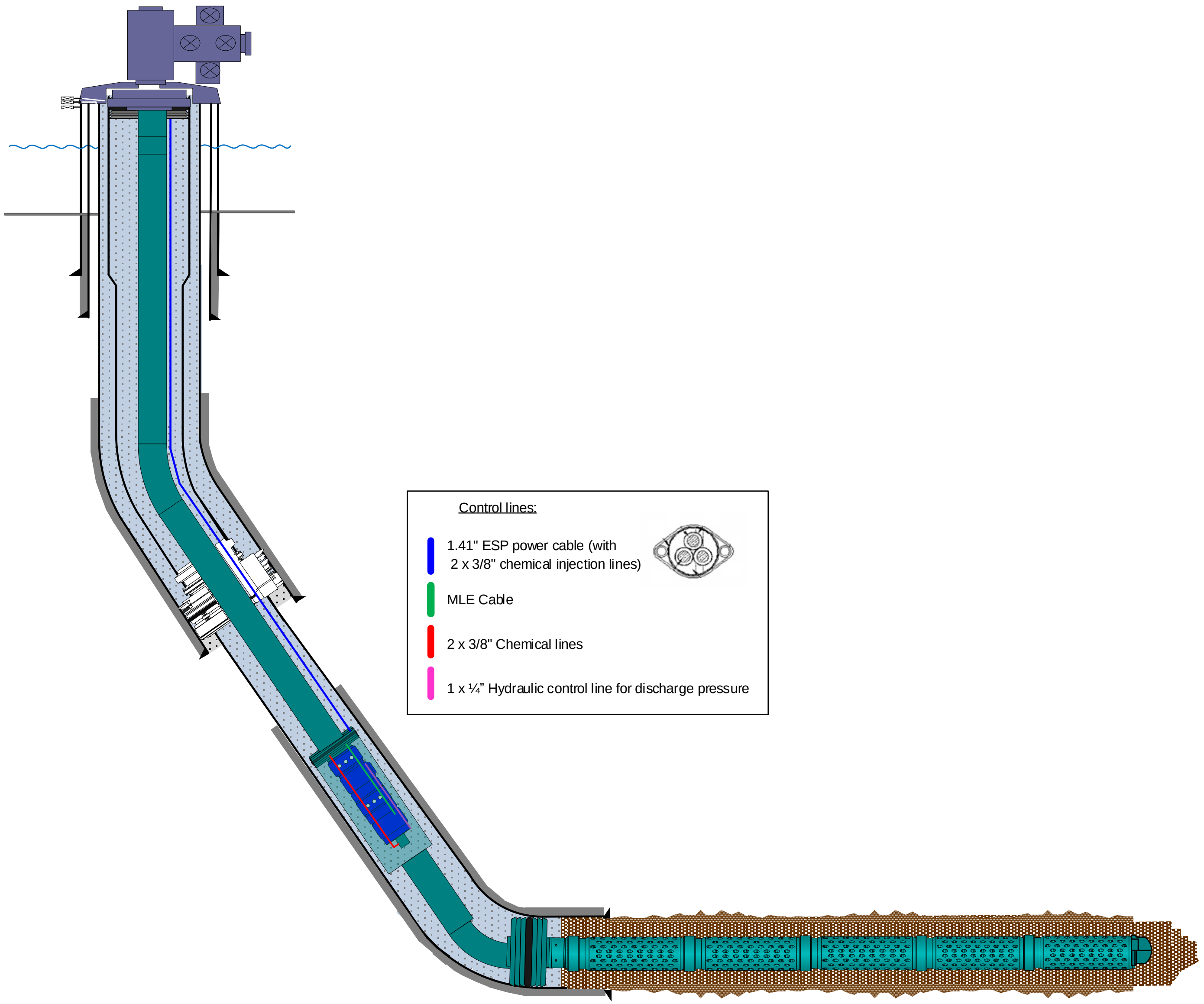
Upper Completion | Standard Design

- 5-1/2" L80 production tubing.
- 9-5/8" ESP production packer.
- Diverter valve above ESP string.
- 675 series pumps driven by 1100HP tandem motors.
- Two independent chemical injection systems.
- Formation isolation valve installed in the middle or lower completion.
- Shifter assembly installed in the tailpipe below the ESP string.
- Middle completion required depending on casing shoe and ESP setting depth.



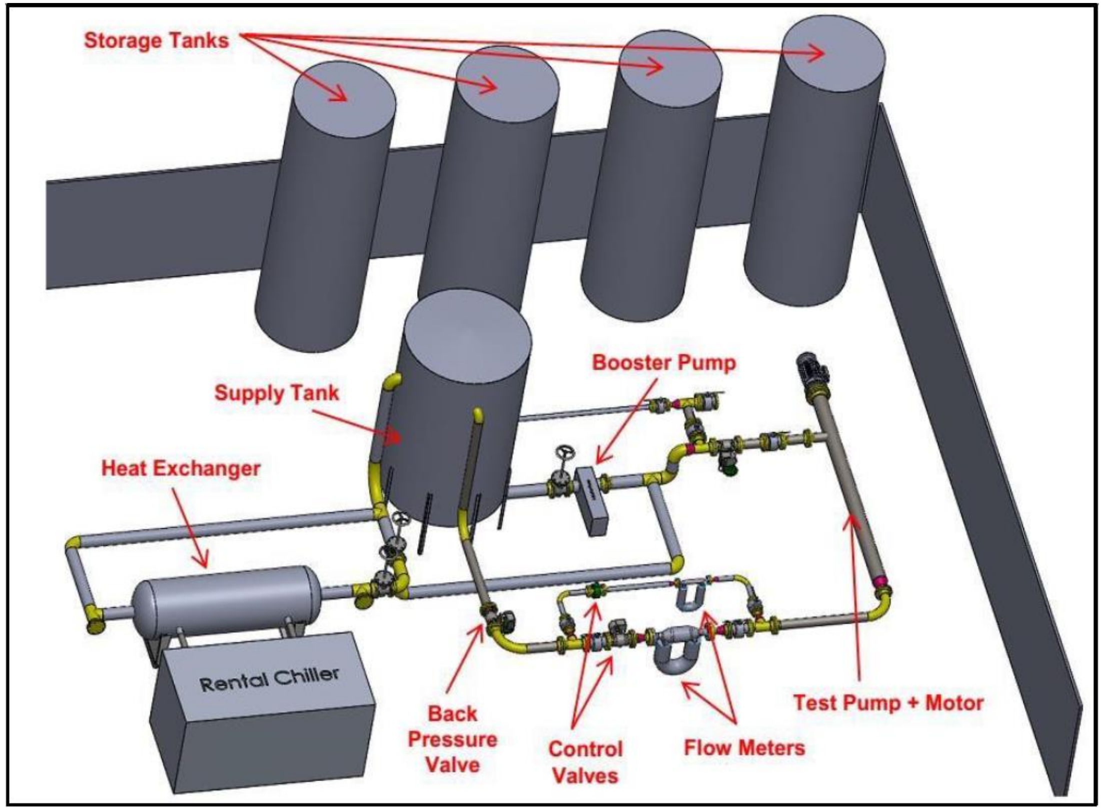
Upper Completion | Improvements

- Encapsulated ESP design.
  - ESP installed inside a 7-5/8" capsule.
  - Doesn´t require a packer above ESP string.
  - Allows ESP to be set deeper.
  - Reduces mechanical stress applied to ESP components due to tailpipe weight.
  - Eliminates the need of a middle completion.
  - Compromises production in some cases.
- Production tubing grade replaced with P110.
- Introduction of a control line set packer which doesn´t require plug installation.
- Reinforced downhole gauge and flange design.



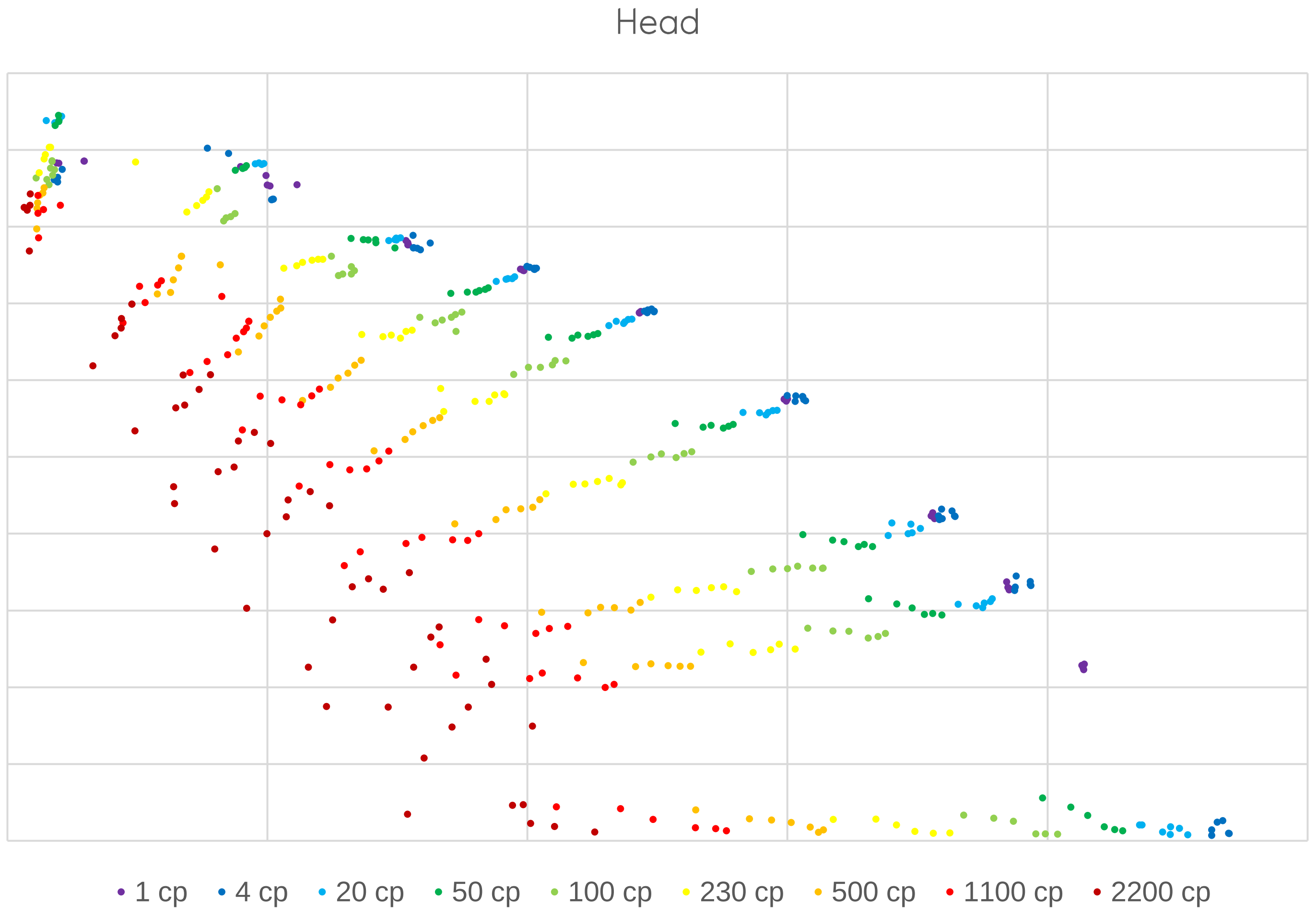
Production Challenges | ESP Performance in Heavy Oil

- Affinity laws don´t hold true for high viscous applications.
- Head and rate are de-rated due to fluid viscosity.
- Excessive power consumption due to low system efficiency.
- Performance models available in the literature are validated with a specific stage type.
- Lab tests limited due to bench constraints.



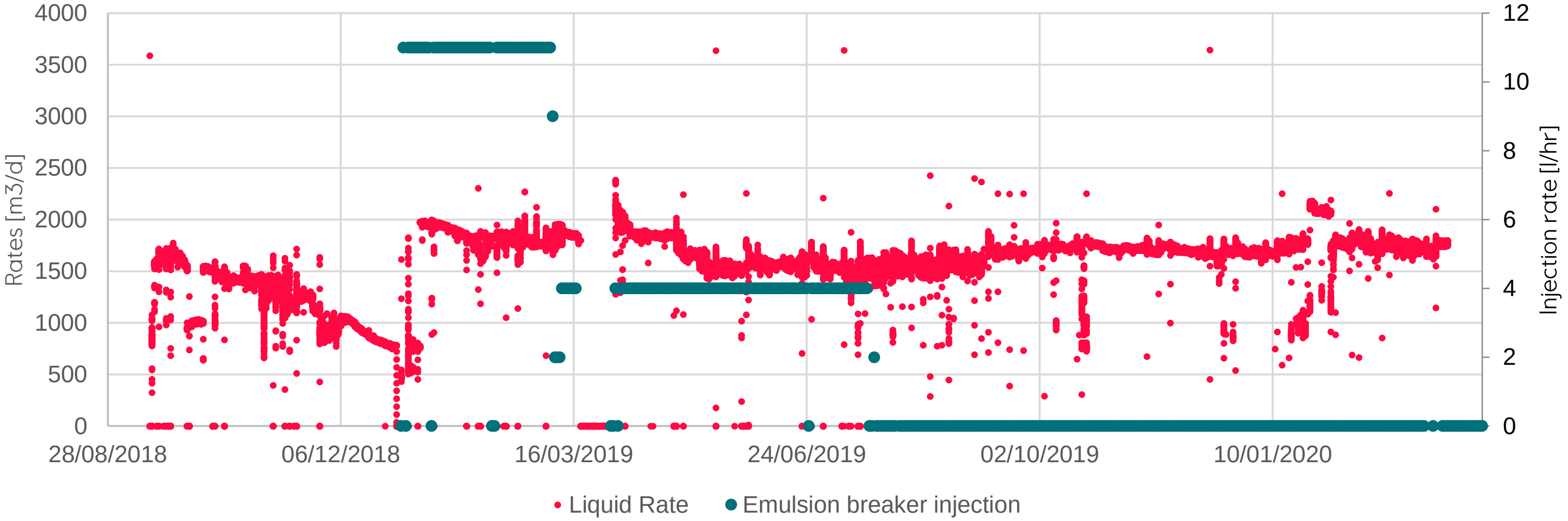
ESP Qualification | Equinor Technical Requirements

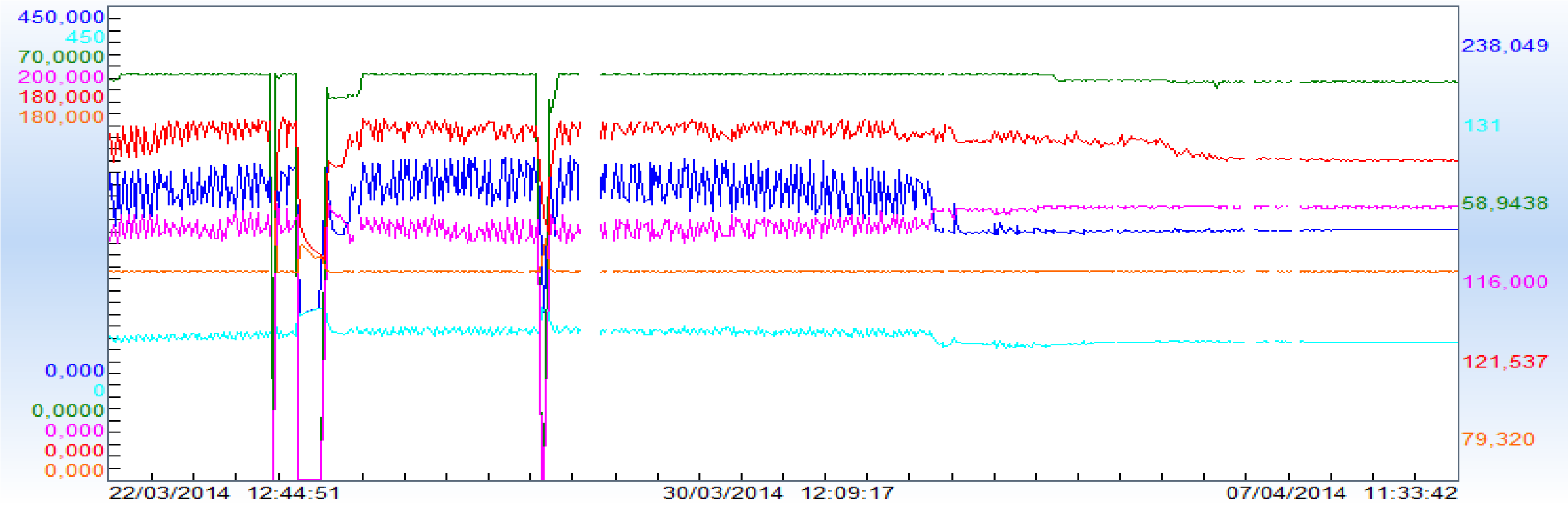
- Each ESP pump type shall be tested with synthetic oil for viscous applications.
- A pump with minimum 6 stages shall be used.
- Viscosity range and operational frequencies are defined by the application.
- System integration test performed in the Product Centre for each string type.
- Stack-up test including completion equipment performed for each string type in Brazil.
- Factory acceptance test performed for every ESP component in Brazil.



ESP Production | Emulsion

- ESP shear forces create emulsion.
- Emulsion viscosity increases up to phase inversion point.
- Higher viscosity degrades ESP performance.
- Emulsion breaker is injected to control emulsion formation.
- Emulsion production creates instability in ESP parameters.
- Pressure and temperature cycles create an ageing effect in downhole equipment.



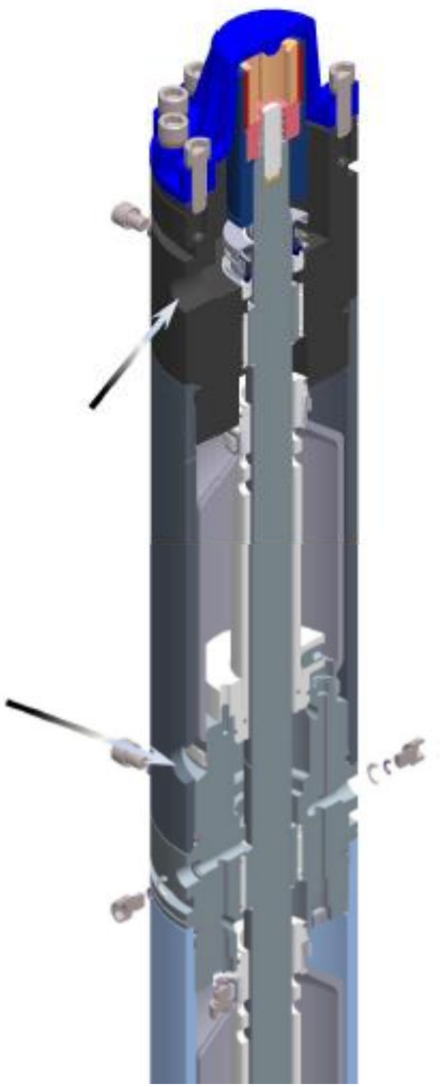


ESP Failure Modes | Packer Penetrator

- Epoxy with cracks leading to phase-phase and/or phase ground failures.
- Fluid contamination inside packer penetrator.
- Signs of overheating noticed during teardown.
- Packer penetrator upgraded to HPHT design.
    - Pressure rating: 10k psi absolute and 5k psi differential.
    - Temperature rating increased to 180 deg C.
    - Insulation materials improved.
- 38 HPHT packer penetrator installed in Peregrino without any failure.

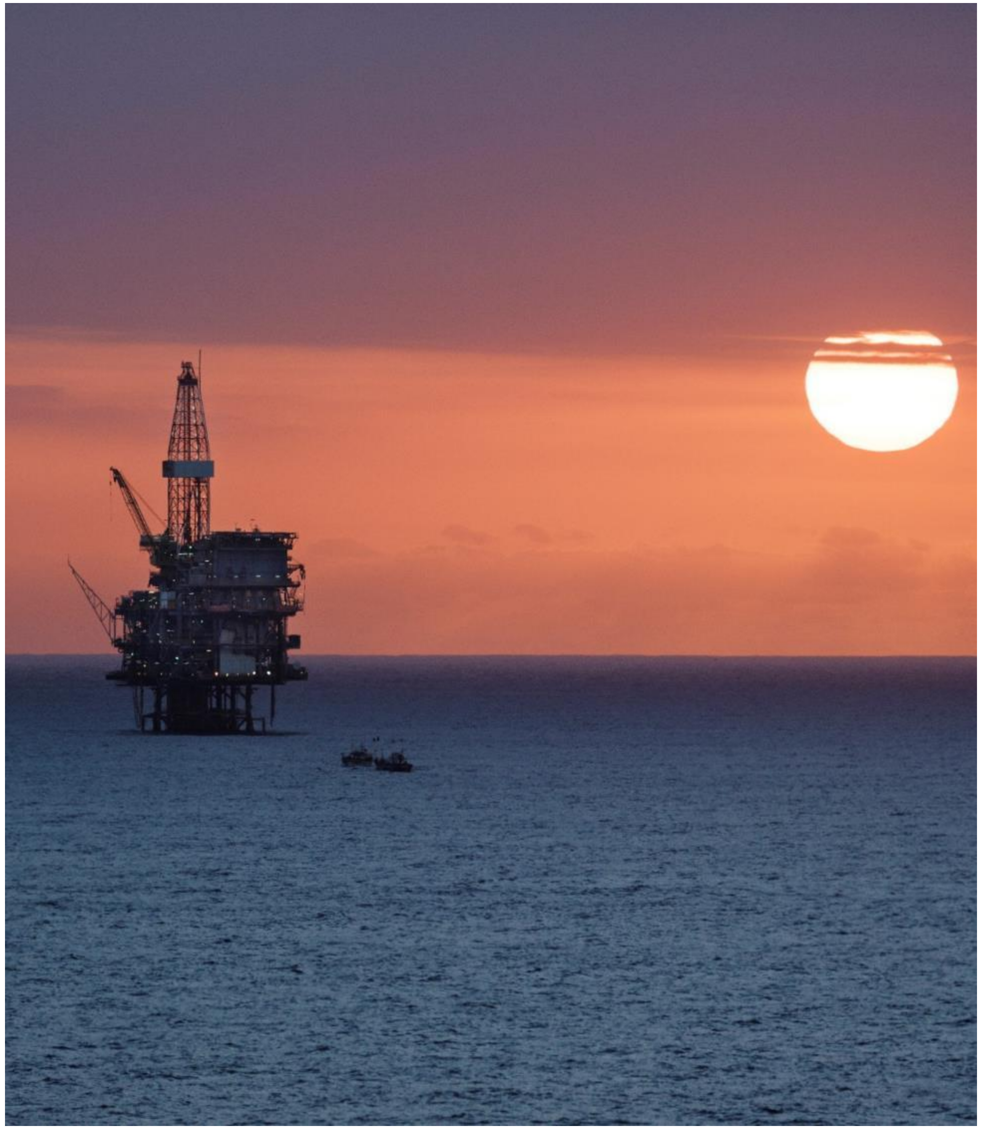
ESP Failure Modes | Asphaltene Precipitation

- Created by chemical instability between dielectric oil and heavy crude.
  - Bag expansion capacity reduced.
  - Check valves plugged.
  - Mechanical shaft seal operation compromised.
- Asphaltene resistant seal design
  - Particle expulsion holes in top chambers.
  - Communication holes in housing.
  - High pressure check valves.
  - Anti-asphaltene additives added to seal section oil.



Peregrino Operation | Way Forward

- Continue failure analysis focus and introduction of new technology.
- Close partnership with Universities and Research Centres to better understand ESP performance in viscous applications.
- Evaluate improvements achieved by the implementation of the performance based contract.
- Deploy ESP discharge temperature reading in 100% of the wells.
- Implement ISO 15551 qualification.
- Achieve consistent 3 years run life in the field.
- Eliminate premature failures.



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