Progressing Cavity Pumping Systems Overview with a Focus on Coalseam Gas Applications

SPE Queensland Brisbane

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Outline

• PC Pumping Systems History and Introduction
• CSG Applications & Differences from Mainstream PCP
• Pumps
  – Elastomers
  – Geometries
  – Pump Sizing and Testing
• System Design and Configuration
  – Pump Assemblies
  – Surface Equipment and Monitoring & Control
  – Drive Strings
• Common Pump Failures and Other Problems
• Summary
Artificial Lift Technologies

- Plunger Lift
- Foam Lift
- PCP
- Rod Lift
- ESP
- Hydraulic Lift
- Gas Lift
Artificial Lift Market Share by Type
(based on dollars spent)

From Spears Oilfield Market Report, Oct, 2011
PCP System Estimated Well Count – 70 to 80K
Progressing Cavity Pump History

Late 1920’s: • Rene Moineau develops the concept for a series of helical gear pumps one of which is what is now known as the progressing cavity (PC) pump

Early 1930's: • Moineau licensed several major manufacturers in the US, UK and Germany; as surface fluid transfer pumps, wide range of displacements but low pressure

Late 1950’s: • Downhole motors (power sections) developed for oilfield drilling applications

1960’s and 70’s: • Experimentation with PC pumps for oilfield downhole artificial lift (AL) applications in Russia & California

1979 to 1981: • Initial trials of PC pumps in Canadian cold sandy heavy oil applications (CHOPS)
Early Canadian PCP Trials

- Initial Canadian ALS trials were in Lloydminster CHOPS heavy oil wells where other artificial lift methods had all failed due to extreme conditions
  - Initial sand cuts up to 30% declining over time to single digit %’s
  - Viscosities between 5,000 and 50,000 cp
  - Shallow directional wells (500 m) with low producing pressures (<200 psi)
- First systems were built from short surface transfer pumps welded together
  - 4 and 10 m³/day/100 RPM with 600 m of lift
  - 2 7/8” outside diameter, cavity portion was only 2 to 4 m long
  - operating torque <100 ft*lbs; axial load <2,000 lbs; power <5 hp
  - The standard for surface pumps was left hand rotation so continuous sucker rod used to avoid connection back-off
  - Surface drive equipment was belt driven direct drive had no recoil control/braking systems
Initial Canadian PCP Challenges

• Many pumps failed due to severe component wear or the stator burning up due to running dry (pump off) or excessive $\Delta P$
• Initial problems with pump quality as there were no inspection or test methods in place
  – Some pumps didn’t produce fluid after installed downhole; rudimentary test benches built to allow a simple performance test to verify fluid rates at a range of $\Delta P @$ pump speed
  – Stator elastomer debonding - they even tried square stators in an attempt to hold the elastomer mechanically
• Manufacturing improvements to increase reliability and safety were gradually implemented
  – Methods to build longer stators to avoid having to weld together many sections
  – Right hand pump versions developed to allow use of sucker rods
• Hydraulic drive heads with valves to control recoil were developed
Canadian Heavy Oil PCP Evolution

• PC pumps specifically designed for artificial lift began to be developed and the capabilities of the systems increased and by 1984:
  – Pump displacements of up to 30 m³/day/100 RPM & pressure ratings of up to 1000 m of head;
  – Full operating torques of up to 200 ft*lbs with associated surface power requirements of up to 10 hp

• In the mid and late 1980’s the use of PC pumps in Canadian heavy oil expanded in terms of different operating companies and equipment suppliers
  – Pump & surface drive technology continued to evolve as did application designs and operating practices resulting in performance improvements

• By late 1980’s several thousand systems operating in Canadian heavy oil and use beginning to expand to other regions
PC Pumps Move Beyond Heavy Oil

- As PCP technology showed good results in heavy oil and their advantages as an ALS system became established in the late 1980’s they began to be tested in other applications such as medium crude oil and US coalbed methane.

- These applications brought forth new challenges:
  - Further increases in volumes and pressure capability as well as different pump geometries to handling varying completions.
  - Medium nitrile elastomers showed limited resistance to med/light oils so work began on new oilfield elastomers.

- By early 1990’s pump capacities had increased to 100 m³/day/100 RPM and lifts to 2000 m; operating torques to 1000 ft*lbs & required power to 60 hp.

- Surface drive equipment capabilities grew to keep up with pump but with lower viscosity/deeper wells rod string recoil became a more significant consideration although initially was poorly understood.

- By 1995 the PC pump installed base had grown to 15,000 wells.
1995 to 2005 Rapid PCP Expansion

• By 1995 PC pumps had become recognized as a viable form of artificial lift for a variety of applications and a rapid expansion period began
  – Wide range of products from increasing number of suppliers
  – Design software and technical literature/training courses developed

• PC pump capability doubled to 200 m³/day/100 RPM and 3000 m lift (not simultaneously)

• Surface equipment improved in terms of ability to safely manage rod string recoil

• Installed PCP system base growing rapidly increasing to approximately 50,000 systems
2005 to 2015 Diversification, Structure & Growth

- Growth in size of systems slowed as they ran up against well completion constraints
- Advancements came more in terms of “fit for purpose” application solutions
  - Improvements in elastomers for higher API oil applications
  - ESPCP’s, insertable systems, charge pumps
  - Metallic pumps for high temperature
- ISO 15136 PCP standards developed in attempt to implement some structure in the industry
- Large new growth areas including Venezuela Faja high volume heavy oil and Australia coal seam gas (CSG)
- Installed PCP system base estimated in 2014 at 70,000 to 80,000
## PCP Capabilities Now and Then

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<td>Max Lift (m Lift)</td>
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<td>Deployment Methods</td>
<td>Tubing</td>
<td>Tubing, Insertable</td>
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</table>
Surface Equipment

- Drivehead
- Stuffing box
- Pumping tee
- Polished rod
- Rod string

Downhole Equipment

- Rod coupling
- Rod string
- PC pump
- No-turn device
Progressing Cavity Pump

- Positive displacement pump
- Two key components:
  - **Rotor:**
    - Typically metal with hard chrome coating
    - Helix of “n” lobes
    - Only moving part
  - **Stator:**
    - Generally made with elastomer with an internal shape as an helix of “n+1” lobes
    - Stationary housing
PC Pump Theoretical Displacement (Capacity)

\[ V = A \times P = 4 \times e \times d \times P \]

- **V**: Theoretical Displacement
- **A**: Cross section area
- **e**: Eccentricity
- **d**: Rotor Diameter
- **P**: Stator Pitch Length

For convenience expressed as a capacity in m³/day/100 RPM or BPD/100 RPM
PC Pump Flow Rate

Theoretical Flow Rate = Capacity x Pump Speed

- Fluid leakage (slippage) across the rotor/stator seal lines between cavities results in actual flow rates that are lower than the theoretical
  - Slippage increases with differential pressure and also depends on the rotor/stator fit, pump speed and fluid viscosity

Actual Flow Rate = Theoretical Flow Rate - Slippage

Volumetric Efficiency = \( \frac{\text{Actual Flow Rate}}{\text{Theoretical Flow Rate}} \)
PC Pump Pressure (Lift) Rating

- PC pump cavity pressure ratings reflect the maximum recommended differential pressure across the rotor stator/seal

  - Typical value of 65 to 75 psi/pitch but can vary significantly depending on pump geometry and elastomer

Rated pressure = quantity of stator pitches x cavity pressure rating

- PCP system designs normally target a 50 to 85% pressure loading

\[ \Delta P = 6 \times 66 = 396 \text{ psi} \]
PCP Nomenclature and Standards History

- PC pumps are not designed or built to an API product specification like sucker rods (11B) and sucker rod pumps (11AX)

- Suppliers had complete flexibility on design, ratings and nomenclature and published limited information

- PCP specific processes such as elastomer/fluid compatibility testing, pump testing and sizing were not consistent across the industry

- Poorly defined quality control standards and documentation

- Lack of structure impacted the credibility of the products & industry

- Difficult for users to compare and evaluate products as more suppliers came on stream
PCP ISO 15136.1 & 2 Standards

- ISO 15136.1 & 2 standards for PC pumps and driveheads developed by joint supplier/user committees

- Includes requirements for design, design verification and validation, quality, nomenclature, performance ratings, functional verification
  - does not define a product specifically like an API specification

- Annexes include recommended practices for PCP specific processes like elastomer/fluid compatibility testing and pump testing

- Enables users to do “apples to apples” comparisons

- Users can specify during purchasing validation, quality and functional testing grades that the supplier must comply with

- Adoption is not required by suppliers and users but in last several years standards are seeing increased use
PCP System Advantages

- High system energy efficiency (between 55% & 70%)
  - Even when handling highly viscous fluids:

- Ability to produce highly viscous fluids (up to 100,000 cp)
  - Its geometry can be designed to offer maximum flow area and low fluid velocity – minimize emulsion formation

<table>
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<th>Fluid</th>
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<td>Water</td>
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<td>Motor Oil SAE 40</td>
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<tr>
<td>Glycerin</td>
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<tr>
<td>Honey</td>
<td>10,000</td>
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<tr>
<td>Ketchup</td>
<td>50,000</td>
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</table>

- No valves or reciprocating parts ⇒ will not gas lock
PCP System Advantages

- Excellent resistance to particulate matter
  - Intermittent pumping of up to 60% sand in liquid
  - Rotor rolling motion gently presses particle into stator elastomer and then releases particle back into flow.
  - Rotor wiping motion does not trap sand.
PCP System Advantages

- Relative low capital and operating cost
  - High efficiency
    - Smaller components
    - Lower power consumption
    - System simplicity ⇒ fewer components
    - Steady energy demand (non-cyclic)
    - Low maintenance
    - Simple installation and operation
- Potential for high turndown ratio (rate flexibility)
- Deployable in remote locations without power
- Green: low profile, low footprint, low noise
There is just one “but” for PCP systems
There is just one “but” for PCP systems

It is the most difficult to apply and least forgiving artificial lift method!
PCP Application – Do Design “Homework”

• Elastomer Selection
  – Produced fluid*
  – Abrasives
  – Temperature

• Pump Geometry Selection
  – Well completion
  – Fluid characteristics
  – Operating conditions

• Pump Sizing and Rotor Fit

*May require elastomer/fluid compatibility testing
PCP Optimization – Learn from Experience

- Monitor and review pump and system operating characteristics
  - volumetric efficiency
  - surface torque
- Evaluate pump run times and intervention reasons
- Perform detailed inspections and failure analysis on pulled equipment
  - a lot can be learned in particular from the pump
- Validate design inputs and assumptions
- As required modify pump and/or system selection & design
  - certain cases may warrant new product solutions
- Repeat the process…
PCP Limitations

• Elastomers and bonding systems
  – Aromatics (swell)
  – CO₂ (explosive decompression)
  – H₂S (hardening)
  – Hot water (debonding)
  – High temperatures (hardening)
  – Run dry (rapid hardening/debonding)

• Rod strings
  – Rod strength limits due to combined axial & torsional loads
  – Rod-tubing wear in directional well bores

• Volume and lift capacity
  – Pump diameter (casing/tubing) and length (handling)
  – Operating speed limitations
PCP Limitations – Capacity & Lift (Tubing Deployed)

Maximum values of lift (depth) and volume (rate) can not be achieved simultaneously. Operating envelop limited by casing size.
Where do PCP systems provide the best value?

- Cold heavy oil production with sand (CHOPS)
- High volume heavy oil production
- Medium oil production
- Oil production in cost sensitive applications from 600 to 2000 meters
- Coalbed methane/Coalseam gas wells, especially if solids present
- Remote locations via gas driven systems
- Problem wells where other ALS have failed
- Sensitive areas requiring low profile surface equipment
PCP Suitability for Coalseam Gas Applications

- Excellent solids handling
- Gas producing capabilities
- Rate flexibility with single pump
- High overall system efficiency
- Relatively low capital and operating cost
- Potential to operate in non-electrified areas
- Low profile and noise
CSG Differences from Mainstream PCP Apps

- Absence of oil in fluid stream and associated lack of lubrication
- Different types of solids (frac sand, coal fines, interburden)
- Potential for very low pump intake pressures
- Required production rates can vary significantly over time
- Continual presence of gas potentially at high GLR’s at intake
- More cost sensitive
Australia CSG Differences from Past US CSM

• Higher required water removal rates and lower decline rates
  – 50 to 800+ m³/day vs 1 to 100 m³/day

• Higher produced water temperatures
  – 50 to 60°C vs 25°C

• Higher gas production rates

• Higher solids production including interburden material production in some fields

• Presence of directional wells

• Lower cost sensitivity
  – CBM extreme low cost requirements

• Distance from main area of PCP and related equipment suppliers and access to experienced personnel
History and Introduction Questions
PC Pump Elastomers - Introduction

• internal elastomeric stator lining is most critical PC pump element
  – Its unique characteristics distinguish PC pumps from other AL systems but also limit their performance and application range

• downhole PCP’s use almost exclusively nitrile polymers due to their oil resistance
  – medium (30-39%) or high (40-51%) acrylonitrile levels

• other ingredients and degree/nature of cross-linking significantly impact elastomer properties and corresponding behavior

• elastomer formulating involves balancing numerous parameters including processability, bonding, fluid compatibility, various mechanical properties and material cost

• pump suppliers develop their own unique proprietary elastomers
PCP Elastomers – Interaction with Fluids

- elastomers interact with the downhole fluids (liquids & gases)
  - chemical interaction can change the polymer structure but does not typically impact physical dimensions
  - physicals effects involve elastomer absorption of liquids and/or the liquids extraction of elastomer components changing physical dimensions and impacting mechanical properties
  - gas penetrates elastomer slowly through diffusion/dissolving processes but upon pressure reduction can’t escape quickly enough and expands in elastomer
    - expands ~10x from 1000 psi to 100 psi
- selecting the appropriate elastomers and understanding and adjusting for its interaction with the fluid downhole is essential to maximizing the performance and longevity of a PCP system
PCP Elastomers – CSG Applications

• Water swells nitrile elastomers but has negligible impact on mechanical properties
  – rate and magnitude of swell increase with temp.
  – produced water chemistry can also impact swell

• CSG produced gas which is primarily CH$_4$ typically will not cause severe explosive decompression damage but can result in numerous small entrained bubbles that effective tighten (swell) the stator as well as small surface blisters

• General purpose medium nitrile elastomers have traditionally been used for CSG but in Australia there are instances of swollen stators and high torques causing operational problems
  – specialty low swell/gas resistant elastomers are being trialed
Elastomer/Fluid Compatibility Testing

• process of exposing elastomer samples to well fluids under simulated downhole conditions and measuring changes to the elastomer to assist in elastomer development, selection and pump sizing

• Elastomer specimen configuration and procedural variables can dramatically alter test results
  • recommended PCP standard procedures in ISO 15136.1 Annex A
Elastomer Swell in CSG Produced Water

**Bar Chart:**
- **X-axis:**
  - Std Medium Nitrile
  - Std High Nitrile
  - Specialty High Nitrile
- **Y-axis:**
  - Volume Change (%)
- **Legend:**
  - Company #1/ Field A/ Well 1 @ 50C
  - Company #2/ Field A/Well 1 @ 50C
  - Company #2/ Field B/Well 1@ 50C
  - Company #2/ Field C/Well 1 @ 50C
  - Company #2/ Field D/Well 1@ 50C
  - Company #3/ Field A/ Well 1 @ 55C
  - Company #3/ Field B/ Well 1 @ 55C
  - Company #3/ Field C/ Well 1 @ 55C
  - Company #1/ Field B/ Well 1 @ 55C
  - Company #1/ Field B/ Well 2 @ 55C
  - Company #4/ Field A/ Well 1 @ 55C
  - Company #4/ Field B/ Well 1 @ 55C
  - Company #1/ Field C/ Well 1 @ 60C
  - Company #1/ Field C/ Well 2 @ 60C
  - Distilled Water @ 60C

**Legend Note:**
- **168 hrs with 2 mm tensile specimens**
PCP Elastomers – Impact of Gas

- Standard elastomer/fluid compatibility testing typically done with dead fluids so impact of gas is not considered

- Special gas autoclaves can be used to soak elastomer or stator sections with liquid/gas and then depressurize
  - Inspect test specimens and characterize gas damage and measure volume change

- Volume change in gas test is not representative of downhole conditions since normally can only measure at ambient pressure
  - Does enable ranking of elastomers in terms of gas resistance
Elastomer Lab Compatibility versus Stator Swell

- use of laboratory fluid/elastomer compatibility results for rotor sizing depends on ability to relate results to PC pump stators
  - Pump models have different thicknesses and within an individual model there are variations in thicknesses
  - Stators only exposed to fluid from internal surface
  - Stators constrain volume change to center

- Fullscale stators exposed to fluids for extended periods and internal dimensions measured periodically over time to establish swell correlations
  - Can also performance test to determine swell impact on operating properties
Elastomer Lab versus Stator Swell - Correlation

60C water with standard medium nitrile elastomer
Pump Geometry: 1.56” minor & 0.68” major thickness

Graph showing the correlation between exposure time and decrease in diameter for different measurements (Stator Minor Absolute Change, Stator Major Absolute Change, Stator Minor % Change, Stator Major % Change, Tensile Lab Specimen % Change).
Elastomer Bonding

• Bonding agents are used to secure the elastomer to the stator tube with agents chemically matched to the specific elastomer
  – Bond strength ideally stronger than elastomer and often tested as part of stator quality control process

• Detachment of the elastomer from the tube (debonding) usually results in rapid pump failure

• Fluid exposure particularity at elevated temps can deteriorate bond systems over time
  – Fluid/bond integrity testing can be used to evaluate potential

• Produced water in CSG applications is not prone to causing bonding issues unless temperatures exceed 80 to 90C
PCP Geometry - Introduction

- Single Lobe (1:2 geometry) conventional elastomeric pumps makes up over 95% of installations

- Fundamental single lobe geometry defined by the pitch (P), minor diameter (d) and eccentricity (e) and that provides the potential to generate a range of geometric permutations for the same pump capacity
  \[ V = 4edp \]

- “Fit for Purpose” geometries exist for specific applications and their unique associated requirements

- Suppliers typically have their own proprietary geometries that are not interchangeable
PCP Geometry - Alternatives

- **Uniform Thickness Pumps**
  - Same internal geometry but with helically shaped housing to create even wall elastomer
  - Thermal expansion is more uniform and potentially less swell on minor lobes
  - Often utilize high cavity pressure ratings
  - More expensive to manufacture/difficult to size

- **Multilobe Pumps**
  - Most commonly modified elliptical 2:3 geometry
  - Potential for higher fluid rates
  - Higher nutation speeds generate higher vibration and elastomer flexing frequencies
  - More expensive to manufacturing/difficult to size
PCP Geometry – Design Considerations

- Pump Capacity
- Pump Pressure/Lift Configurations
- Intended Cavity Pressure Rating
- Operating Speed Range
- Maximum Torque
- Casing and Tubing Constraints
- Insertable
- Coilable
- Length limitations for max lift configurations
- Fluid characteristics (viscosity, abrasives, lubricity, gas)
- Rotor and stator manufacturability
- Cost
PCP Geometry - Variations

- PC pump geometries are characterized by a variety of design parameters and indexes but they have limited meaning to users.
- Visual comparison of geometry more intuitive approach to evaluation.
PCP Geometry Selection

- Short pitch wide cross-section geometries with low cavity pressure ratings for low speed pumping of high viscosity abrasive slurries
  - Typically higher friction and lower runlife
- Standard pitch wide cross-section geometries for low to moderate speed pumping of moderate to high viscosity fluids or moderate to high speed pumping with high required lifts or shorter pump lengths
- Standard pitch/cross-section/cavity pressure rating (general purpose) for moderate to high speed pumping of non-viscous liquids
- Long pitch narrow geometries for moderate to high speed pumping of high flow rates of non-viscous liquids without abrasives
  - Typically lower friction and higher run-life
- Lower eccentricity/larger minor diameter configurations if a strong (high torque) rotor is required
- Insert pump geometries due to space constraints are typically long narrow geometries with higher cavity pressure ratings
PCP Geometry For CSG

- select pump capacity to enable higher speed operation to avoid stick-slip and minimize hydraulic torque for given rate
  - Rate=Capacity*Speed & Hyd Torque=DeltaP*Capacity

- less aggressive geometries seal with lower interference resulting in lower friction torque and also have lower elastomer stresses and hysteretic heat build-up which minimizes fatigue and extends runtime
  - if high levels or slugs of solids then a slightly more aggressive geometry may assist with moving them through the pump

- select geometries with rotor profile strengths that enable operation at high frictional torque levels
Pump Sizing/Rotor Fit Introduction

- *Pump Sizing* is the process of matching a rotor and stator to generate successful pump performance and life in the downhole application

- determines the nature of fit between the rotor and stator
  - normally rotor > stator therefore interference fit

- typically done on an individual pump basis due to the stator dimensional variations that:
  - are inherent in manufacturing process
  - occur in downhole environment due to fluid and thermal effects

- since rotor sizes are more controllable they are adjusted to fit with the stators
Pump Sizing – Designing for Elastomer Changes

- *Pump Sizing* must consider downhole condition impact on elastomer and associated stator dimensions and accommodate to provide optimal pump performance
Pump Sizing Importance

• performance and life of a PC pump is largely determined by the interaction between the rotor and stator at the seal lines which is controlled by pump sizing

• **short term**: dictates pressure seal/capability as well as pump friction and operating torque/power

• **long term**: controls internal elastomer stresses that impact crack initiation/growth and subsequent fatigue failure
  
  • controls elastomeric hysteretic heat generation which degrades the elastomer & bond system
  
  • impacts nature of rotor/stator wear which is also a common failure mode
Pump Sizing History

• during initial use primary concern was pump moving fluid to surface
  • lack of dimensional control in the stators
  • ability to measure stators was limited or nonexistent

• adopted simple pump performance tests with water at room temperature to confirm flow rates
  • if got bad result would select different rotor and retest

• attempted to correlate pump test results to pump performance in field and repeat what worked (“trial & error”)

• pump tests with objective of achieving target result was the first form of pump sizing/rotor fit
Pump Testing Equipment and Processes

- test equipment rotates pump at a fixed speed moving water or oil from a reservoir through a valve to restrict flow and create back pressure

- measure pump output flow rates (and calculate volumetric efficiency) and torque at multiple back pressure levels and produce curves

- test processes often not well controlled and measurements unreliable and prone to operator adjustment leading to poor test repeatability
  - lack of consistent equipment/processes between suppliers

- ISO 15136-1 Annex C includes a comprehensive PC pump testing standard covering instrumentation, test process and result documentation
  - large gap relative to historical & existing equipment
ISO 15136 Compliant Pump Testing

- ISO 15136 compliant test equipment and processes becoming more common
  - extensive instrumentation
  - semi-automated control (no operator influence)
  - high level of accuracy and repeatability
  - test reports include a lot of detail
Pump Testing Repeatability

Same Stator & Rotor
Tested 5 times
Test Speed: 300rpm
Test Temp.: 30°C
**PC Pump Test Report**

**Test Location:** Banca de Teste PCP_04

**Pump Information:**
- **Pump Serial #:** 58-0600-32P003043-3356800007 W-M-115 2.53611.775
- **Shaft Serial #:** 1174104042
- **Nominal Capacity:** 80
- **Electromotor Code:** M-W-115
- **Shaft Complete Length:** 2134 404317
- **Motor Type:** Hollow
- **Motor Make:** 2.736
- **Motor Make Code:** 28.995

**Test Parameters:**
- **Test Location:** Vila Longoita, BR-4414
- **Test Fluid:** Water
- **Date Tested:** 26/09/13 10:01:36
- **Time Temperature:** 36
- **Test Type:** N/A
- **Test Location:** Vila Longoita, BR-4414
- **Test Fluid:** Water
- **Test Temperature:** 36
- **Test Condition:** N/A
- **Lower Limit:** 90
- **Upper Limit:** 90
- **Test Pressure (psi):** 11.9011.70: Fluid Delivery 3

**Test Results:**

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**Test Chart:**

- **Efficiency/Flow Rate & Torque vs Differential Pressure**

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**Final Result:**
- **Approved**

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**Specifications & Actual Values:**
- **Test Temp. (°C):** 30 / 30
- **Test Speed (rpm):** 300 / 300
- **Max Pressure (psi):** 1150 / 1150
- **Balanced Lift (ft):** 105 / 105
- **Torque @ Balanced Lift (lbf-ft):** 521 / 521
- **Fluid Rate @ Balanced Lift (gpm):** N/A / N/A
- **Efficiency (%):** 50 / 50
- **% of Rated Pressure (%)**: N/A / N/A

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PC Pump Sizing Evolution

• pump tests as a form of pump sizing and means to establish rotor fit remains common today but:
  – applications more challenging with downhole conditions very different than the test bench and setting sizing targets more complicated and subjective
  – tendency has been toward narrowing the efficiency target as opposed to understanding if it is the right target

• Evolution towards measuring rotor and stators and using results to calculate rotor interference fits and relate directly to anticipated downhole changes in stator dimensions
PC Pump Component Measurement

- rotor dimensions well controlled and usually accurately measured as standard practice with average values reported on pump test reports

- stator has inherent dimensional variations and difficult to accurately measure non-destructively so historically not done
  - some suppliers have developed custom tools and are measuring as standard practice (ISO 15136 Q1 requirement)
PC Pump Stator Measurement Data
PC Pump Sizing – Calculating Fits

- accurate rotor and stator measurements enable pump sizing through calculations of rotor/stator interference fits
  - absolute values or % elastomer compression

<table>
<thead>
<tr>
<th>Model</th>
<th>Stator Major Diameter (inches)</th>
<th>Stator Minor Diameter (inches)</th>
<th>Rotor Major Diameter (inches)</th>
<th>Rotor Minor Diameter (inches)</th>
<th>Major Int. (inches)</th>
<th>Minor Int. (inches)</th>
<th>Major Int. (%)</th>
<th>Minor Int. (%)</th>
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<tr>
<td>Small</td>
<td>2.500</td>
<td>1.250</td>
<td>1.895</td>
<td>1.281</td>
<td>0.011</td>
<td>0.038</td>
<td>2.2</td>
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<tr>
<td>Large</td>
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<td>2.375</td>
<td>3.592</td>
<td>2.425</td>
<td>0.011</td>
<td>0.061</td>
<td>2.2</td>
<td>2.1</td>
</tr>
</tbody>
</table>

- with accurate reliable measurements and test bench can develop understanding of cause and effect relationship between pump sizing and performance as well as predictive relationships
  - high level of sensitivity between rotor sizing/interference fit and pump test performance
PC Pump Sizing – Test vs Measurement Correlation

Standard Test Rotor
Test Speed: 300 rpm
Test Temp.: 30°C

Eff. vs. MMT Correlation: $R^2 = 0.74$

- Vol. Efficiency at Rated Lift
- Pump Torque at No Load

Stator Minor Diameter (inches)

Pump Torque at No Load (ft•lbs)

Volumetric Efficiency (%)
• pump suppliers typically have their own proprietary techniques for selecting fits in support of sizing

• multitude of sizing scenarios and fits potentially yield same test efficiency but often produce differences in other characteristics that impact pump performance & life
PC Pump Sizing – Application Considerations

• key premise of pump sizing is predicting and accommodating for:

1) pump operating conditions
   • most important are speed, pressure loading and fluid viscosity

2) downhole stator changes
   • temperature impact on stator dimensions predictable with elastomer thermal expansion coefficients
     • occurs *instantaneously* but pump temperature can change with time due to internal heating
   • fluid swell impact on stator dimensions can be assessed via lab fluid/elastomer compatibility tests but must be able to correlate lab coupon results to stator
     • occurs *gradually* over time so if size for equilibrated conditions then may be too loose initially
PC Pump Sizing – CSG Considerations

• Application considerations
  – Higher speeds, higher pump pressure loading, low fluid viscosity, solids production and poor fluid lubrication
  – Swell due to water and potentially entrained gas
  • Some wells sit for extended periods before initial start-up

• Initial sizing for standard medium nitrile elastomers based on historical experience (20 to 40% efficiency at rated lift, 300 RPM & 50C)
  – field experience with high torques along with pulled pump retests and measurements confirmed under estimating downhole swell likely due to gas effects

• Reductions in sizing of 0.040 to 0.080” interference being used with improved results (0% at half of rated lift, 300 RPM & 50C or less)
  – trials with lower swelling elastomers to reduce size adjustments
Pump Questions
PC System Design and Configuration

- PC pumps act as part of a system that to operate efficiently and reliably must be designed and configured in an integrated manner.
- Variety of options for the downhole pump assembly and the other major system components to cover the wide range of PCP applications.
- Suppliers and other third parties offer a variety of software tools to help with system design and analysis.
PC Pump Downhole Assembly

- Most common are tubing deployed systems where the stator is run on the tubing string and rotor on the drive string
  - Tagging assembly used to position the rotor within the stator
  - No-turn tool or anchor often used to prevent tubing back-off
- Insertable systems where the rotor and stator are run together on the drive string provide the potential for well servicing time/cost reductions by avoiding tubing pulls
  - Stator is landed and locked in position typically via pump seating nipple and seating rings to prevent pump spinning or moving
- Can be difficult to land in high angle directional wells
  - Potential to become stuck and not retrievable if a lot of solids
  - Synergies with downhole gauges since can stay in place
  - Lower pump volume x lift capacity and less geometry flexibility as stator is constrained by tubing inside diameter
PC Pump Assemblies – Insertable Systems

![Graph showing Maximum Lift (m) vs Volumetric Capacity (m³/d/100rpm) for different tubing sizes: 2 7/8”, 3 1/2”, 4 1/2”, 5 1/2”.

Key components:
- Tubing
- Pump Seating Nipple
- Seating Mandrel
- Extension Tube
- Pull Rod
- PC Pump
- Tag Bar
- No-Turn Tool

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PC Pump Assemblies – Downhole Driven

- Rod less systems typically referred to as ESPCP’s and driven by downhole motors
- Typically used in highly directional wells or offshore wells where rod strings cause problems
- PC pump is directly coupled to the electric motor through a gearbox/flex-shaft assembly
  - Gearbox ratios of 4:1 to 15:1 reduce the high motor speed to a PCP range of 150 – 500 rpm
- Electric motors typically ESP motors (2-poles, 3500rpm)
  - Recently PMM (Permanent Magnet Motors) that eliminate need for gearbox
- Cost is considerably higher than rod driven systems and number of installations relatively limited
PC Pump Assemblies – Charge/Recirculation Pump

• Tandem dual pc pump rod driven configuration
  – large volume/low lift pump at the bottom (charge pump)
  – lower volume/high lift pump at the top (production pump)
• In gassy applications the lower pump compresses the fluid to feed the upper pump which runs at higher efficiency
• In applications with solids a perforated joint is placed between the two pumps and the lower pump recirculates the fluid in the pump intake area to keep solids from settling out
PC Pump Assemblies – Elastomerless (metal)

- Elastomeric component of the stator is replaced by metal
- Mainly used in high temperature (up to 350°C) and severe aromatic environments that cannot be handled with elastomers
- Rotor/stator clearance fit results in higher fluid slippage and lower volumetric and overall efficiencies
- Poor solids handling capability
- Cost is much higher than elastomeric PCP’s
PC Pump Assemblies for CSG

- Conventional single-lobe elastomeric tubing deployed configurations are most common

- Insertable systems seeing increased use due to potential to reduce servicing costs by enabling pump replacements and pump size changes without tubing pulls
  - Can be difficult to seat in shallow directional wells
  - Instances of removal problems due to solids
  - Insufficient capacity for some high water rate wells

- Potential to run a large capacity tubing deployed pump and then after failure or when too large pull the rotor and install a smaller capacity insert into the tubing above the original pump stator
PCP Surface Drive – Basic Functions

- Suspend the rod string and carry the axial loads
- Deliver the torque necessary to drive the PCP
- Provide for safe release of the stored energy during shut-downs
- Prevent produced fluids from escaping the system
- Support the prime mover (hydraulic or electric)
- ISO 15136.2 standard covers surface drives including braking system design validation
PCP Surface Drive – Common Configurations

Electric Drive (Belt or Gear)

Hydraulic Motor and Power Unit for Non-Electrified Locations (Inline motor, Belt or Gear)
PCP Surface Drive – Recoil Control

• During operation PCP systems can store a significant amount of energy
  • Strain energy in rod string
  • Potential energy in fluid column
• Energy is released upon shutdown by spinning backwards and if uncontrolled can reach high speeds (>1000 RPM) and result in risk to equipment and personnel
• Early surface drives had basic braking systems (or none at all) but shallow wells and small pumps did not create problems
• As PCP systems grew in capacity brake system designs have evolved increasing in complexity and reliability
  • If properly selected for application are effective at safely managing backspin
PCP Motor Controllers

• **Fixed Speed Controller**
  – On/off designed with basic torque protection based on motor loading
  – Some are capable to auto-restart

• **Variable Speed Controller (“VSD” or “VFD”)**
  – Enables motor speed adjustment with turndowns of up to 10:1 manually or based on external signals (e.g., pressure, slow)
  – Remote communication and control capability
  – Local data logging
  – Accurate torque overload protection
  – Advanced functionality including restarts, power loss ride thru and DC hold/braking
PCP Surface Equipment Selection Considerations

- Torque Requirements
- Axial Loads (often surface drives have multiple thrust bearing options)
- Speed Range (and how adjusted)
- Power Requirements
- Braking System Reliability
- Stuffing Box Design
- Controller Functionality and Features
- Footprint and Noise
- Maintenance (hydraulic and belt driven higher than geared)
- Capital and Overhaul Costs
PCP Surface Equipment for CSG

- CSG applications are not particularly demanding in terms of surface equipment
  - Low to moderate operating torques, axial load and power
  - Shallow wells and smaller tubing size minimize recoil severity
- Variations in fluid rates over time require systems with high speed flexibility (turndowns)
- Large numbers of wells makes footprint, low maintenance and low overhaul costs important
- Electric gear and sheaved systems are common but non-electrified areas require use of hydraulic systems
PCP Monitoring and Control - Introduction

• Surface torque monitoring and high level shutdown is critical for drive string and surface drive protection
  – Hydraulic configurations monitor system pressure
  – VFD’s monitor motor loading electronically

• PC pumps due to their elastomeric lining are sensitive to being run dry and may fail within a few hours

• Difficult to monitor fluid levels or even pump off through surface load (torque) measurement due to unpredictability of pump friction and lack of torque signatures upon pump off until too late
PCP Monitoring and Control – Downhole Gauges

- Downhole gauges used to collection information for optimization & run dry protection
  - Data for monitoring start-ups and shutdowns including surface drive brake performance
  - Valuable for troubleshooting failures
- Most common is temperature and pressure but vibration is also available and can be used to avoid harmonic pump speeds
- Typically deployed for PCP’s via tubing string gauge mandrel short distance above the pump
  - potential to monitor both pump intake and discharge
- Gauges must be designed for PCP vibrations to ensure reliability
- Historically cost has prevented their widespread use in PCP’s but lower cost systems along with positive experience has resulted in increased use especially for systems with high cost of failure
PCP Monitoring and Control – PCP Gauge Data
PCP Monitoring and Control - Surface

- Surface monitoring can provide shutdown control or basic optimization
- Sensors placed in flow line to measure flow rates or lack of flow
  - Various types of flow devices (e.g., wedge, magnetic)
  - Thermal probes
- Typically need to be calibrated for the application or even specific well
  - Multiphase flow conditions can be difficult to manage
- Solids production can damage some types of sensors
- Lower cost systems seeing increased use in applications where well suited such as CSG
PCP Monitoring and Control for CSG

• Torque control is important to protect drive strings given potential for torques higher than design due to elastomer swell and solids production

• Downhole gauges provide information for optimization and reliable protection against rod dry scenarios
  – instances of early gauge failures

• Surface flow control is showing promise as a lower cost option but systems are still being fine tuned for CSG applications
PCP Drive Strings

- Transmits torque and power from the surface drive to the downhole pump
- Carries axial pump load as well as self weight
- Loading condition is torsional and axial but torsional dominates therefore no benefits to tapering
  - Cyclic bending loads occur in areas of wellbore curvature
- Shear coupling often included above the pump to allow rod to be pulled in event of stuck rotor or insert pump
- Configuration above pump must avoid restricting pump orbital motion and causing fatigue or wear problems
- ISO 15136.3 in development for PCP drive strings
PCP Drive Strings – Conventional Sucker Rods

• Conventional sucker rods are commonly used in PCP applications
  – 1” Grade D typically rated at ~1000 ft*lbs
• Many conform with API 11B but also custom PCP designs
  – Larger 1 ¼” and 1 ½” bodies for high torque (up to 3750 ft*lbs)
  – Modified connection designs for higher torsional strength
  – Offset designs for low profile
• Special PCP designs for centralizing couplings or rod guides to mitigate rod/tubing wear
  – Spin thru designs are the most effective
• Connections are common cause of PCP interventions often with higher frequencies than the pump
  – proper make-up procedures are critical due to the torsional loads and recoil events
PCP Drive Strings – Continuous Sucker Rods

• Smooth rod with no couplings except one at top and bottom
  – Various sizes and grades up to 2500 ft*lbs
• Distributes contact and reduces loads about 75x relative to concentrated loads on conventional sucker rod
  – results in significant reductions in tubing wear rates
• Reduces tubing pressure losses due to less restrictive flow
• Reduces bending stresses due to uniform stiffness
• Major enabler to success of PCP systems in sandy heavy oil directional wells
PCP Drive Strings – Continuous Sucker Rods

• Stored and transported on custom reels
• Installed via special service equipment with injector systems
  – Fast install and pull rate (up to 30 m/min) can provide economic benefits and integrates well with insertable pumps
PCP Drive Strings Selection Considerations

- Required torque capacity
- Tubing size restrictions
- Tubing flow losses
  - If viscous fluids or high flow rates relative to tubing size
- Directional wells
  - Rod/tubing wear and rod bending fatigue
- Cost and Availability
PCP Drive Strings for CSG

- Conventional unguided sucker rods are adequate for vertical wells
  - Typically 7/8” and 1” Grade D although high strength provides additional capacity for larger pumps or to work through solids

- Shear couplings are recommended if high solids and stuck rotors

- Connection make-up is critical to avoid backed off rods

- Rod string/tubing wear is a problem in directional wells due to high doglegs (over 10 deg/30 m), solids and poor lubrication
  - Continuous rod is reducing tubing wear rates but may require tubing rotators to achieve multi-year runs
  - Sucker rods with multiple spin-thru guides are having success

- High doglegs in directional wells may result in conventional rod bending fatigue failures at high revolution counts
Common Pump Failures and Other Problems

- Common Pump Failures
- Other Common Problems
  - High Torques
  - Rod/Tubing Wear
  - Solids Production
PC Pump Failures – Worn Elastomer

- Characterized by rough elastomer surface with horizontal wear lines
  - May be large tears or pits and embedded particles
- Wear reduces interference fit and results in high fluid slippage and low volumetric efficiency
  - Rotor coating wear may also be present & contributing factor
- Normal process but accelerated by produced fluids with abrasive solids and higher pump speeds that increase revolution count
- Mitigation options:
  - Larger pumps run slower
  - Abrasive resistant elastomers
  - Geometries with low sliding or flow velocities
PC Pump Failures – Swollen Elastomer

• Characterized by severe tightening of internal stator dimensions and potentially softening of elastomer
• Swell causes increased pump start-up and operating torque and often progresses to fatigue failure
• Normal process due to fluid/elastomer interaction
• Mitigation options:
  – Compatibility testing to match elastomer to produced fluids
PC Pump Failures – Elastomer Fatigue

• Characterized by cracks and missing elastomer pieces primarily on the seal line but no excessive elastomer hardening
  – may be progressive top to bottom
• Compromises the seal line and results in high fluid slippage and low volumetric efficiency
• Normal process due to repeated flexing of the elastomer but accelerated by tight rotor/stator fits and higher pump speeds
• Mitigation options:
  – Change elastomer to reduce swell and/or reduced pump sizing/rotor fit
  – Less aggressive pump geometry
  – Reduced differential pressure
  – Reduce free gas at pump intake
  – Larger pumps run slower
  – Fatigue resistant elastomer
PC Pump Failures – Elastomer Hysteresis

• Characterized by elastomer hardening on the minor lobe with in severe cases material vaporization (“blow-out”)
• Compromises the seal line and results in high fluid slippage and low volumetric efficiency and may also produce high torque
• Abnormal process indicative of severe interference and flexing frequency (speed) combination
• Mitigation options:
  – Change elastomer to reduce swell
  – Reduced pump sizing/rotor fit
  – Reduce cavity pressure by pump with more lift or reduced
  – Larger pumps run slower
  – Elastomers with better dynamic properties
**PC Pump Failures – Elastomer Gas Damage**

- Characterized by bubbles in the elastomer matrix, blisters and in severe cases large cracking and debonding
  - may be progressive top to bottom
- Compromises the seal line and results in high fluid slippage and low volumetric efficiency and can produce high torques
- Normal process due to gas migration into elastomer and expansion during shut-downs that cause depressurization
- Mitigation options:
  - Gas resistant elastomer
  - Minimize depressurization cycles
  - Reduce gas entering pump
PC Pump Failures – Burnt Elastomer

• Characterized by severe hardening and cracking of the elastomer surface
• Compromises the seal line and results in high fluid slippage and low volumetric efficiency and may also produce high torque
• Abnormal failure indicative of pump run dry due to insufficient liquid or restricted intake or discharge

• Mitigation options:
  – Monitor fluid levels
  – Avoid pump blockages
  – Reduce free gas at pump intake
PC Pump Failures – Debonded Stator

• Characterized by large sections of detached elastomer or in severe cases a bare stator tube

• Compromises the seal line and results in high fluid slippage and low volumetric efficiency and may also produce high torque

• Abnormal failure indicative of incompatibility between produced fluid and elastomer bond or exceeding bond temperature ratings
  – May also be manufacturing defect

• Mitigation options:
  – Compatibility testing to match elastomer to produced fluids
  – Ensure operating below elastomer/bond max. temperature
Common Problems – High Torque

• May prevent restarts, cause power shutdowns on high torque (or drive string breaks) and reduces overall system efficiency
• Assuming proper design calculations will be attributed to friction
• Pump friction is the most common cause and can be due to:
  – Liquid or gas elastomer swell
  – Incorrect pump sizing/rotor fit
  – Viscous pump torque from viscous flow through restricted cavity
  – Hardened or large sections of detached elastomer
  – Rotor running on tagging assembly
• Other potential causes:
  – Excessive tubing flow losses due to flow restrictions
  – Rod/tubing contact torque due to high contact loads
  – Rod resistive torque due to viscous fluids
Common Problems – Rod/Tubing Wear

• Most common problems are tubing holes but may also wear connection or rod body resulting in drive string failure
• Typically only a problem in directional wells with severity increasing with build rates and doglegs
• Sand cut accelerates wear rates as does poor lubrication
• Failures a function of wear rate and revolutions so slower pump speeds will prolong failure
• Continuous sucker rod or conventional rods with centralizers and/or spin thru guides can help mitigate problems
• Tubing rotators spread wear around tubing circumference
• Rod lifts with conventional sucker rods change wear locations
PC Common Problems – Solids

• Accelerates wear of pumps and drive strings and tubing in directional wells

• Potential for slugs of solids to accumulate in pump and create high pump torques
  – Size rods/drives for excess torque capacity
  – Select pump geometries with good sand handling

• Potential to settle on top of the pump or during shutdowns causing increase torques and potentially block pump outflow
  – Ensure tubing sized for minimum transport velocity
  – Avoid shutdowns or flush after shutdowns

• Potential to settle out in sump and block pump intake
  – Utilize paddle rotors and slotted intake assemblies
  – Charge pumps with ported sub to keep solids in suspension in pump intake region
Summary

- PC Pumping Systems began as a solution for Canadian sandy heavy oil wells but their use has expanded rapidly into numerous other countries and different applications
  - Wide variety of equipment configurations now available
- Advantages such as viscous fluid and sand handling capabilities, higher overall efficiency, small footprint and relative low cost make it the preferred ALS option for many applications
- Not as forgiving as other ALS systems so equipment design and selection is critical particularly elastomer selection and pump sizing
- ISO 15136 standards are helping to alleviate historical lack of definition and standardization of product designs, ratings and nomenclature that created confusion and impacted credibility
- Technology is still relatively young and opportunities for further advancements although becoming more challenging
  - Collaborative supplier/user efforts important for success
Final Questions and Closing

thank you very much

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