Hydraulic Dewatering:
Technology, Performance, and Applications

7th European Gas Well Deliquification Conference

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Hydraulic Dewatering
Cormorant Engineering Background

- Started in 2008 Cormorant Engineering began developing and testing Hydraulically Operated Dewatering Pumps for Natural Gas Wells
- Combining the knowledge of a Coiled Tubing Specialist and a Hydraulics Specialist have created a new line of Dewatering pumps for Natural Gas Wells:
  - Vertical / Horizontal and Deviated Well Bores
  - Well depths to 4500m
  - Well Temperatures: 10°C to 160°C
  - Production Rates: 0 – 100+ BWPD
- In the process of developing the new pumps Cormorant Engineering also developed:
  - Finite Element Based Predictive Model for Hydraulic Dewatering Pumps
  - A One of a kind Test Facility for performance testing the hydraulic pumps
    - Simulates downhole conditions for testing pump operation
  - Cormorant Experience is in North America
Hydraulic Dewatering System
What is it?

Three major components
- Surface Hydraulic Power Unit (HPU) with Power Optimized Hydraulics (POH)
- Hydraulic Fluid and Water Conduits – Coiled or Production Tubing
- Hydraulic Down-hole Pump
Hydraulic Dewatering

Benefits

- Coiled Tubing Deployment eliminates rod related problems
  - Tubing wear at deviations
  - Rod parting at deviations
  - Gas locking
- Small Surface Unit can be easily enclosed for noise and appearance
  - 1m x 1m x 1m typical
- Coiled Tubing Rig deployment with most installations taking a few hours
- Operate to 0 Pa (psi) bottom hole pressure
- Minimal Operator adjustments and maintenance
Hydraulic Dewatering presents several challenges to be met:

- **Hydraulic / Water Seal Interface**
  - Cormorant Engineering addressed this most critical challenge by applying years of seal engineering experience, with extensive testing in Coal Fines and Sand.
    - Mean Time to Failure from field analysis – 3.7 years
    - Solution includes proprietary materials and patent pending design concepts.

- **Reliability in Water Pump Section**
  - Cormorant Engineering partnered with Harbison Fischer (Rod Pump Market Leader), to provide the water pump section of the Dewatering system.
    - Years and years of reliability and experience
    - Full range of on the shelf, test solutions for almost any well condition
  - Due to the difference in Hydraulic operation versus rod driven pump, special water plunger seals were developed by Cormorant.
Hydraulic Dewatering
Challenges and Results - continued

- **Predictability of performance** – Hydraulically operated pumps have no history for establishing expected performance.
  - Cormorant Engineering developed a Finite Element Model of the surface and downhole system, to provide a design and application tools for the hydraulic pumps.
  - Model has been calibrated and validated with field data and with test data.

- **Performance Testing**
  - Cormorant Engineering developed a one of a kind test facility for testing the performance of the pumping systems.
    - 3000 m coiled tubing
    - 1, 1.25, 2 in Coiled Tubing
    - Simulated Bottom hole conditions
      - 550 bar
      - 100 °C
    - Gas interference test capability
    - Suspended solids Testing
# Hydraulic Dewatering

## Application Segmentation

<table>
<thead>
<tr>
<th>Well Configuration</th>
<th>Hydraulic Action</th>
<th>Depth</th>
<th>Rates</th>
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<tr>
<td><strong>Single Action</strong></td>
<td>1.5H – Hybrid Action</td>
<td>Depth to 1500m</td>
<td>Rates to 25 BWPD</td>
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<td>Rates to 25 BWPD</td>
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<td><strong>Dual Action</strong></td>
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<td>Depth to 2600m</td>
<td>Rates to 25 BWPD</td>
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<tr>
<td><strong>Self Reciprocating</strong></td>
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<td>Depth to 4500m</td>
<td>Rates to 100 BWPD</td>
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- **Tubing Pumps Set in Seating Nipple**
  - Depth to 1500m, Rates to 25 BWPD
  - Depth to 3000m, Rates to 25 BWPD
  - Depth to 2600m, Rates to 25 BWPD
  - Depth to 4500m, Rates to 100 BWPD

- **Casing Pumps Hang from Coiled Tubing**
  - Depth to 2400m, Rates to 20 BWPD
  - Depth to 4000m, Rates to 25 BWPD
  - Depth to 4500m, Rates to 30 BWPD

*Not Feasible in Regions where Casing Flow is not permitted*
Hydraulic Dewatering

Pump Selection

- TTSA – Tubing Pump
  - Single Action
  - 1 Hydraulic Conduit
- TCSA – Casing Pump
  - Single Action
  - 1 Hydraulic Conduit
  - 1 Water Conduit
- DA – Dual Action Pump
  - 2 Hydraulic Conduits
  - 1 Water Conduit
- 1.5 - 1.5Action Hybrid Pump
  - 1. Hydraulic Conduit
  - 1 Water Conduit
- SRP – Self Reciprocating Pump

Pump Selection Chart

<table>
<thead>
<tr>
<th>Production Rate - BPD</th>
<th>Well Depth – 1000m</th>
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<tr>
<td></td>
<td>1000</td>
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<tr>
<td>SRP</td>
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<tr>
<td>DA</td>
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<td>SRP</td>
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Diagram showing the relationship between production rate and well depth for different pump types.
Hydraulic Dewatering Systems

Hydraulic Action Types

- **Single Acting**
  - Hydraulic fluid is used to power the pump one direction, hydrostatic water pressure returns the stroke.
  - Reduced installation costs compared to Dual Acting – One less coiled tubing
  - Production rates of 25 BPD; depends on depths, well configuration, etc.
  - Depths to 2400m TVD

- **1.5 Action**
  - Uses Hydraulic Fluid for power in one direction, uses Pressurized produced Fluid for return. (see animation)
  - Patent Pending Surface System with a fluid isolator
  - Action can be applied to any Single Acting Pump
  - Depths to 4500m TVD

- **Dual Acting**
  - Hydraulic fluid is used to move the pump in both directions
  - Increased longevity & reliability compared to Single Acting
  - Production rates 30 BPD; depends on depths, well configuration, etc.
  - Depths to 4500m TVD

- **Self Reciprocating Pump**
  - Dual Acting Pump
  - Switching Directional Valve Incorporated into down hole Tool
  - Eliminates timing and efficiency losses due to compressing the fluid column each stroke
  - Significantly increase production capacity up to 100 BPD
  - Depths to 5000m TVD
Hydraulic Dewatering Systems

Tubing Pumps

- Land in Seating Nipple
- Water flow through Coiled Tubing
- Gas flow through production tubing
- Hydraulic fluid in concentric coiled tubing
- Feasible to operate with Subsurface Safety Valve

Dual Acting Through Tubing

DATT

Single Acting Through Tubing

SATT

Self Reciprocating Pump

SRP

Single / Dual Acting Wirleline Conveyed

Hydraulic Lines and Water Line on Outside of Tubing

Hydraulic Lines and Water Line on Outside of Tubing

Pump Lands in DB Type Locking Mandrel
Single Acting System

Benefits
- Simple Reliable Design
- Lowest Cost Installation - 1 coiled tubing required for hydraulic fluid
- Depths to 7,000 ft
- Through Tubing or Through Casing version possible
- Redundant seal system provides reliability and life

Operation
- Hydraulic Pressure Forces Piston and Plunger down
- Hydrostatic Head forces Piston and Plunger to retract when Hydraulic Pressure removed

Sizes
- 2 3/8, 2 7/8 Tubing Designs in Production
- 4.5, 5.5 in Casing Designs in Production
1.5 Acting System

- **Operation**
  - Combines a single acting pump (previous slide), with a dual acting hydraulic system.
  - Requires a water / oil isolator with control valves.
  - Power stroke is the same as the single acting system.
  - Return stroke, the oil is applied to the piston in the isolator, forcing the plunger to return, and then dumps the remaining water to the produced fluid storage.

- **Benefits**
  - Increased well fluid production
  - Lowest cost dual acting deployment
  - Increased flexibility in application depth
  - Allows for dual acting pump in smaller production tubing applications
  - Single acting down-hole pump is unchanged, the modification are at surface
  - Patent pending hybrid system that allows for a single acting pump to become a dual acting pump
1.5 Action Pump
Surface System

- 20 Horsepower HPU
- NATURAL GAS ENGINE
- ELECTRIC MOTOR
- WATER ISOLATOR

- PRODUCED WATER SCREEN FILTER
- AUTOMATIC BACKFLUSH
SRP Pump System

- 2 3/8 Through Tubing Pump
  - Center Hold Down – 1.750 in dia.
  - 1.312 Dual Acting Power Piston
  - 1.0 Water Plunger
  - Self Reciprocating Valve System in Down Hole Pump
    - Oil driven pump for maximum life
    - Offers Efficiency of 60%+
- Stainless Steel Coiled Tubing Hydraulic Supply
- Carbon Steel Hydraulic return Coiled Tubing
SRP Pump System

- Hard 88 Rc Sliding Surfaces
- 1000 lbs. shifting force on Spool to overcome contamination
- Two stage system eliminates mid stroke stalling
- 15 strokes per minute
Test Facility
Test Facility

The Test Facility was funded by a major oil & gas company to validate the performance of our pumps and modeling capability.

- **Intensification Cylinders**
  - Simulate Downhole pressures, flow, and compressibility

- **Coiled Tubing Reel**: 5,000 ft of 2.00 inch, 5,000 ft of 1.25 and 5,000 ft of 1.00 inch

- **HPU – Electric and Natural Gas**
  - Single Acting
  - Dual Acting
Test Facility

- **System Layout**

  - Reservoir
  - Pump
  - Control Valve
  - Coiled Tubing

  Pressure Intesifier
  - Input: System Pressure (3000 psi)
  - Output: Input pressure plus Boost Pressure

  Hydraulic Fluid Volume Meter

  Coiled Tubing

  Boost Pressure

  Water Reservoir

  Backpressure control Water Volume Meter

  5000 ft
Test Facility

- Data Acquisition Interface
Predictive Model
Cormorant developed a dynamic simulation model for hydraulic dewatering pumps. The model uses Finite Element Methods and calculates the performance of each element simultaneously. The end conditions are HDP & HPU. It also uses Finite Difference in time Method, where the entire process is repeated at time increments of ~100 ms. The model simulates the dynamic performance of the pump, actuator, flow and losses in each element, hydraulic system inputs, and water production output.
Cormorant Engineering

Hydraulic Dewatering System
Design Report

Pump Model Template

Pump Measured Depth: 3,000ft
Pump True Vertical Depth: 3,000ft
Bottom hole pressure in well: 50psi
Specific Gravity of Water: 1.01

Viscosity of Hydraulic Fluid: 10cSt
Max Hyd Sys Operating Pressure: 3,000psi
Accumulator Volume: 0gal
Accumulator Charge Pressure: 649psi
Time Hyd. Press. Is Applied to First Conduit: 6sec
Time Hyd. Press. Is Applied to Second Conduit: 6sec
Total Time of Each Period: 12sec
Water Backpressure: 0psi
Radial Clearance for Water Plunger: 0.002in

Water Flowrate From Well: 51.6BPD
Slippage Past Water Plunger: 2.0BPD
Water Flowrate Without Slippage: 53.5BPD
Strokes per Minute: 5.0
Balance Hydraulic Pressure: 649psi
Max Pump Hydraulic Power: 20.17HP

Design Results
Field Study – Performance Monitoring

- Model comparison: Predicted vs. Actual
EXAMPLE: 1000 m COAL BED METHANE WELL (SAN JUAN BASIN NM)

- AVERAGE BARRELS OF WATER PRODUCED: 9 BBLs/DAY
- MAXIMUM PRODUCED: 15 BBLs/DAY
- AVERAGE GAS PRODUCTION INCREASE: 110 MCF / DAY
- AT $13.2/MMBTU GAS PRICE:
  - AVERAGE INCREASE IN GAS INCOME: $540,000/YR
- AVERAGE SYSTEM PAYBACK 2-4 MONTHS
Experience

- 600-3,300 m TVD
- Horizontal and Vertical Completion
  - Up to 93° landing position
- Fayetteville Shale, CBM, Alaska Hydrate, and Massard Field in Oklahoma / Arkansas
- Dual CT String FLATpak™, Triple CT String FLATpak™, Single Coiled Tubing, Concentric Coiled Tubing
- 2-3/8” TT Pump up to 5-1/2” TT Pump
- 4-1/2”, 5 1/2” Casing Pumps

Subsurface safety valves are not required on land based wells in North America
- Cormorant is investigating options to address this requirement in Europe
Questions?
Cormorant Engineering LLC

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