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Webinar 7. Plunger Lift and Capillary Deliquification
Darryl Albers
Feb 10, 2015
Weatherford
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Webinar Series
1. Introduction to Artificial Lift Aug 27 '14
2. Reciprocating Rod Lift (RRL) Sep 23 '14
3. Gas-Lift Oct 21 '14
4. Progressing Cavity Pumping (PCP) Nov 19 '14
5. Electrical Submersible Pumping (ESP) Dec 16 '14
6. Hydraulic Lift: Jet Pump & Piston Pump Jan 13 '15
7. Plunger Lift and Capillary Deliquification Feb 10 '15
8. Production Optimization for Artificial Lift Mar 3 '15
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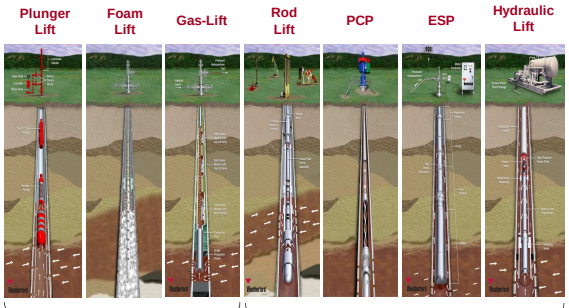
Lift Technologies by Energy Source



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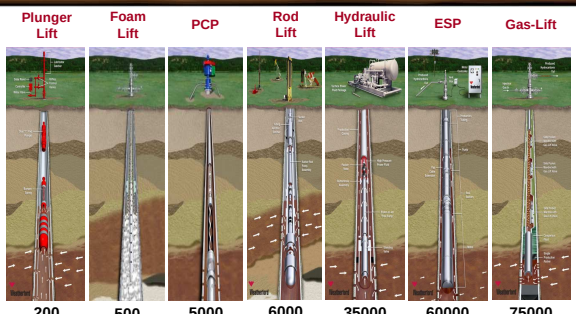
Lift Technology by Lift Capacity



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Plunger Lift

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Plunger Lift Theory

- Method of artificial lift that uses the well's gas energy as the prime mover of liquids that have caused loading

Plunger Lift Animation

Plunger Lift 'Rules of Thumb'

Liquid Production Max

- 200 BBLS/ day

Depth Max

- 19000 ft

Gas Production Required

- 500 scf/ BBL / 1000ft (Packerless)
- **1000 scf/ BBL / 1000ft (Packer)**

Deviation

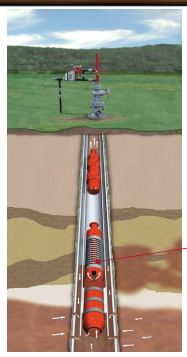
- 60° Inclination
- **4°**/100ft DLS

Pressure Drive

- Use Load Factor

$(P_{CSG} - P_{TUB}) / (P_{CSG} - P_{LINE}) < 0.5$

Components / Parts



Bumper Spring: **Pl**unger's deepest stopping point

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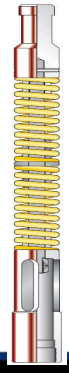
Bumper Springs



Double Spring

Single Spring

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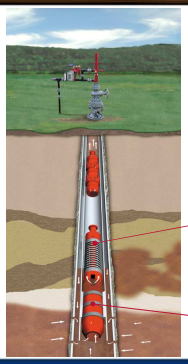
Components / Parts



Bumper Spring: **Pl**unger's deepest stopping point

Landing Tool: Locates bumper spring in profile or lands elsewhere

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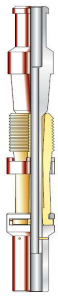
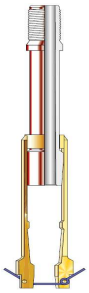
Landing Tools

2 or 3 Cup Holddown

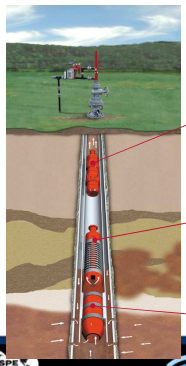


Tubing Stop



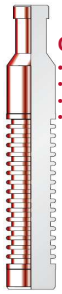
Collar Stop

Components / Parts



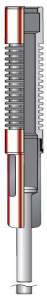
- ***Plunger:*** **Pig-type device that provides seal inside tubing to deliver fluid to surface**
- ***Bumper Spring:*** Shock absorber at plunger's deepest stopping point
- ***Landing Tool:*** Locates bumper spring in profile or lands elsewhere

Plunger Methods



Conventional

- **Used on depleted wells**
- **Shut-in well for plunger to fall**
- **Gas velocities below 10 ft/s**
- **Fall time average 300 ft/min**



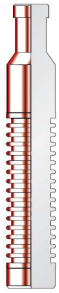
RapidFlo (Continuous)

- **Used at beginning of loading**
- **Minimal or no shut-in time**
- **Gas velocities above 10 ft/sec**
- **Higher amounts of fluid**
- **Fall time average 1000 ft/min**

Ask The Audience:

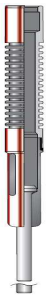
What is the disadvantage that Conventional Plungers have versus Continuous Flow Plungers?

Plunger Types



Ring Plunger

- Available in Conventional & RapidFlo
- Common / Very simple
- Longest Life
- Great paraffin handling
- Good scale handling
- Conventional Ring is most inexpensive lift
- Least sealing efficiency (requires higher flow rates)



Plunger Types

Padded Plunger

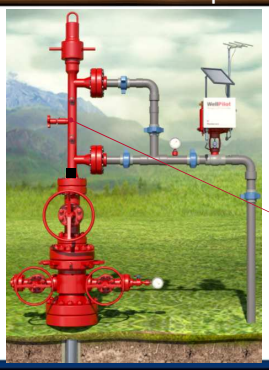
- Most popular plunger
- Higher sealing efficiency than Ring Plungers
- Second best longevity
- Available with one, two, or three, sets of sleeves (each sleeve has four pads on it)
- Not good with movement of solids or paraffin

Plunger Types

Brush Plunger

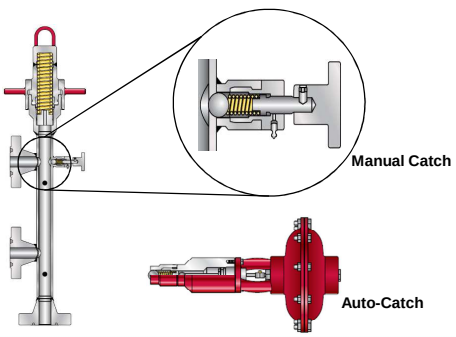
- Highest sealing efficiency
- Has application to move solids
- No moving parts
- Has lowest longevity of all plunger types

Components / Parts

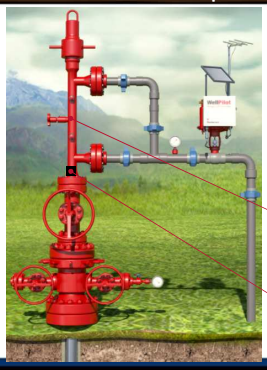


Lubricator: **Uppermost stopping point for plunger**

Lubricator/Plunger Catcher



Components / Parts



- ***Lubricator:*** Uppermost stopping point for plunger
- ***Plunger Sensor:*** Magnetic device strapped around lubricator to detect plunger arrivals

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Plunger Sensor

- Detects the plunger's arrival in the lubricator by completing a dry contact circuit

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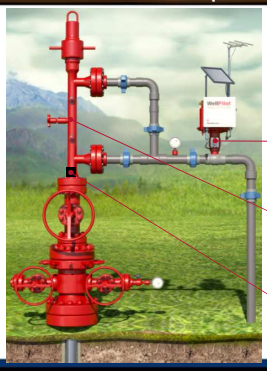
Components / Parts



- ***Motor Valve:*** Diaphragm-operated device that opens/closes sales/tank line
- ***Lubricator:*** Uppermost stopping point for plunger
- ***Plunger Sensor:*** Magnetic device strapped around lubricator to detect plunger arrivals

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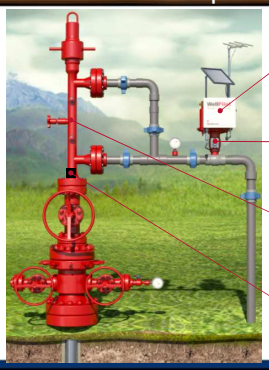
Motor Valve

- **Pressure-activated design opens and closes the flowline**
- **Available in working pressures of 1000, 2000 and 4000 psi**

Components / Parts

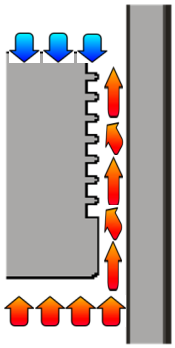


- ***Controller:*** **Electronic-based system with control parameters for opening and closing motor valves**
- ***Motor Valve:*** **Diaphragm-operated device controlled by controller to open/close sales/tank line**
- ***Lubricator:*** **Uppermost stopping point for plunger**
- ***Plunger Sensor:*** **Magnetic device strapped around lubricator to detect plunger arrivals**

Controller

- **Passive** – Time Only
- **Reactive** – Self Adjusting
- **Proactive** – Real Time Optimization

Plunger Theory



- Gas below the plunger acts on the plunger both in gas pressure on the bottom area of the plunger as well as friction on the sides of the plunger from bypassing gas flow

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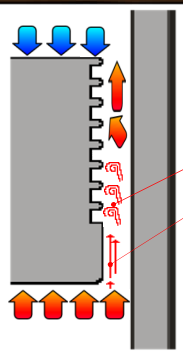
Plunger Theory



- Spiral Interface designed to encourage Turbulent flow instead of Laminar to increase gas friction and seal efficiency.

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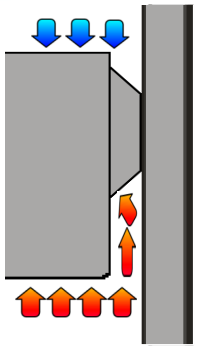
Plunger Theory



- Padded Interface creates higher sealing efficiency requiring less gas velocity to achieve lift
- Higher Pressure below the plunger ensures constant upward gas migration and minimal fluid fall back during plunger trip

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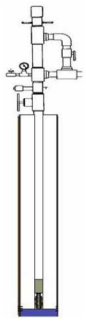
Plunger Lift Cycle

Loaded

- Well shuts in
- Plunger falls through liquid

Plunger Lift Cycle



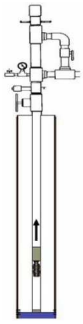
Build Up

- Plunger lands on BHBS
- Fluid above plunger
- Pressure builds

Plunger Lift Cycle

Unloading

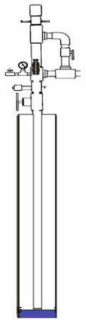
- Master Valve opens
- Gas acts on plunger
- Plunger arrival starts
- Plunger lifts liquids



Plunger Lift Cycle

Afterflow

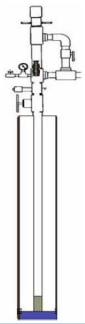
- Fluid arrives
- Plunger arrives
- Gas flows



Plunger Lift Cycle

Loading

- Sales time continues
- Liquid builds up
- Flow rate declines



EVALUATIONS

Evaluations

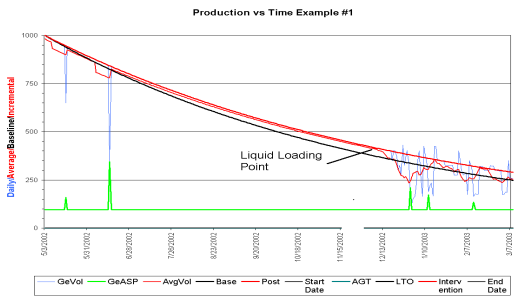
Questions that Evaluations Answer:

- Is the well under-performing?
- Is liquid loading the cause?
- Is the well able to support a Plunger Lift System?
- What are the set points for start-up?
- What further concerns need to be addressed?

Evaluation Steps

1. Establish Decline Curve
2. Calculate Critical Velocity
3. Calculate Critical Rate
4. Ensure Liquid Loading
5. Calculate Flow Velocity
6. Calculate Foss & Gaul
7. Calculate Slug Size
8. Calculate Operating Parameters

Decline Curve



Critical Velocity

Turner Equation:

$$V_c = 1.593 \frac{\sigma^{1/4}(\rho_{Liquid}-\rho_{Gas})^{1/4}}{\rho_{Gas}^{1/2}}$$

Standard Assumptions that "Simplify" Turner Equation:

- 60 dynes/cm surface tension for water
- 20 dynes/cm surface tension for condensate
- 1073 kgm/m3 water density
- 721 kgm/m3 condensate density
- 0.6 gas gravity
- 120 of gas temperature
- 20% Upward Adjustment

Critical Velocity

"Simplified" Turner Equation:

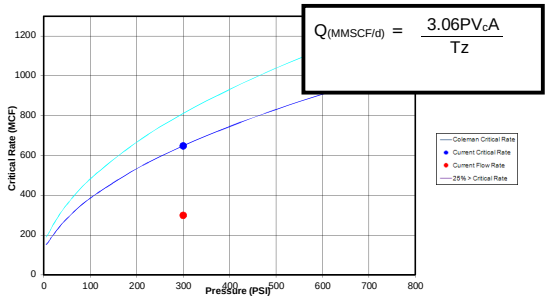
$$V_c = C * \frac{(\rho_{Liquid}-0.0031p)^{1/4}}{(0.0031p)^{1/2}}$$

For Coleman (under 1000 psi): C = 4.43 water, C = 3.36 condensate

For Coleman (1000+ psi): C = 5.32 water, C = 4.04 condensate

Critical Rate

$$Q_{(MMSCF/d)} = \frac{3.06PV_cA}{Tz}$$



NOTE: Calculate this @ Lowest point and ALL Diameters in completion

Liquid Loading

Production Rate < Critical Rate

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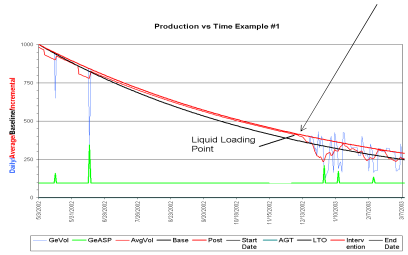
Liquid Loading

Does the calculated loaded rate correspond to the loading point ???



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Flow Velocity

There are two options for Velocity Calculations:

1. Calculate using derivation of rate equation

$$V = \frac{(T+460)z * Q}{3.067\ P * A}$$

2. Calculate using relation to calculated Cv and Cr

$$V = (\text{Estimated Gas Rate} / Cr) * Cv$$

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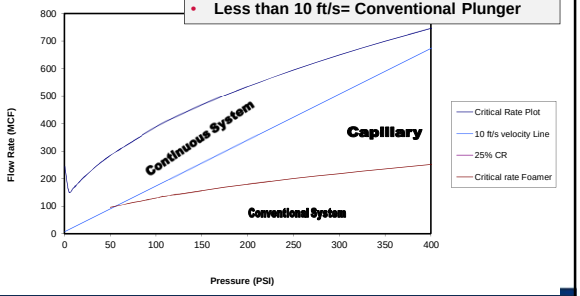
Flow Velocity

Velocity determines the type of plunger:

- Greater than **10 ft/s** (**3 m/s**) = Continuous Plunger
- **Less than 10 ft/s= Conventional Plunger**



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Ask the Audience:

At What Velocity Can You Use Continuous Flow Plunger?

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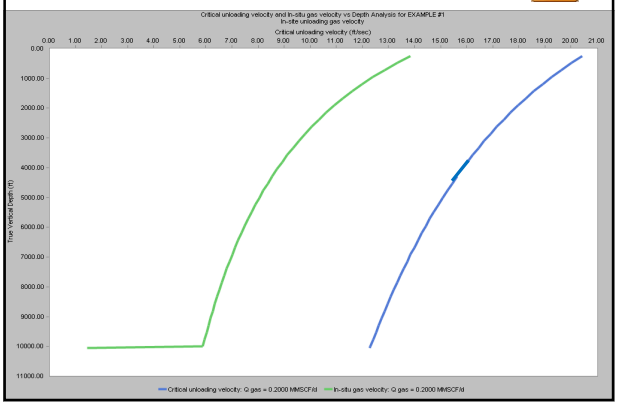
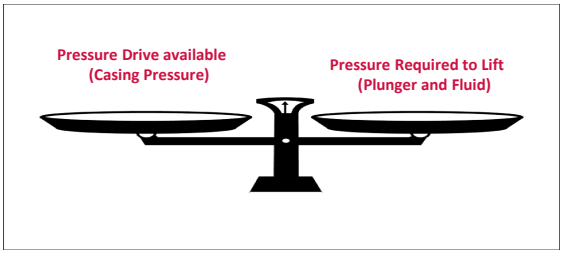
Velocity Plot



Foss & Gaul

F & G is the Force Balance Equation:

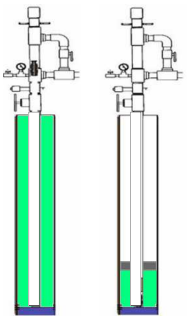


Foss & Gaul Equation

$$P_{cmin}=[(P_{atm}+P_p+P_{lp}+(P_{lw}+P_{lf})\times L)\times(1+(D/K))]$$

- P_{cmin}=Minimum Pressure Necessary to Cycle Plunger
- P_p = Pressure to lift weight of plunger.
- P_{lp} = Flow-line pressure.
- P_{lw}= Pressure to lift weight of liquid per barrel.
- P_{lf}= Liquid frictional pressure loss per barrel.
- L = Load size, bbls
- D = Depth of tubing, ft
- K = Constant to show relationship between tubing size and pressure loses due to friction.

Foss & Gaul – Special Case



Packer Completion

- **Packer reduces Annular Volume significantly leading to higher initial pressure requirements**
- **Adjusted equation is based on volume from packer to BHBS**

Slug Size

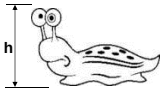
Slug Size Determines:

- Foss & Gaul required pressure
- Build-up time to meet Foss & Gaul requirements
- Fall Time of plunger
- **Cycles per day**

Slug Size

- Non-Gasified Liquid Column

Height = (CP – TP) / (Pressure Gradient * SG)



- Gasified Liquid Column

Height = (CP – TP) / (Pressure Gradient *(1 – Fg) * SG)

* Non Gasified is commonly used in shut in wells

Operating Parameters

Shut-in Time is based on:

- Plunger fall time through gas and through liquid
  - **Based on plunger type and age**
- Safety factor
  - Commonly 10%
- **Required pressure build-up time**
  - Depth of BHBS
  - **Fluid height**
  - Gas volume
  - **Fluid volume**

Cycles per Day is based on:

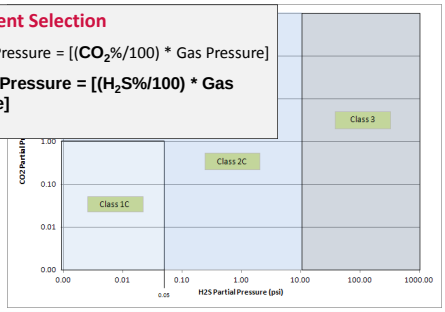
- Rise time
  - **Depth BHBS**
  - Speed of plunger
- **Shut-in time**
  - **Previous slide**
- **1440 minutes/day**

Operating Parameters

* Classification from NACE MR175 ISO15156 Document

Equipment Selection

- Partial Pressure = [(CO_2%/100) * Gas Pressure]
- **Partial Pressure = [(H_2S%/100) * Gas Pressure]**



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Common questions asked?

- Do I Have Enough Pressure To Run A Plunger?
- Do I Have Enough Gas Volume?
- Will A Plunger Run Under A Packer?
- Is My Sales Line Pressure Too High?
- Will It Work In Paraffin?
- What Are My Operating And Maintenance Cost?
- How Long Will It Be Effective?
- Will It Work With Gas Lift?

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Capillary Injection

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Capillary Video

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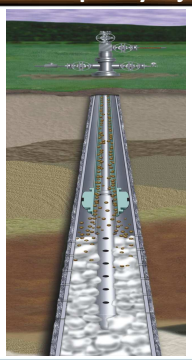
Capillary Injection String Considerations



	Typical Range	Maximum*
Operating Depth	2,000 –12,000' TVD	22,000' TVD*
Operating Volume	5 - 200 BPD	Have unloaded 550
Operating Temperature	100 - 375° F	450° F
Wellbore Deviation	70 ° <12°/100' Build Angle	90° <12°/100' Build Angle
Corrosion Handling	Excellent	
Gas Handling	Excellent	
Solids Handling	Fair to Good	
Application	*Depends on treatment needed	
Servicing	Workover or Capillary Unit	
Prime Mover Type	Wells own energy	
Offshore Application	Good	

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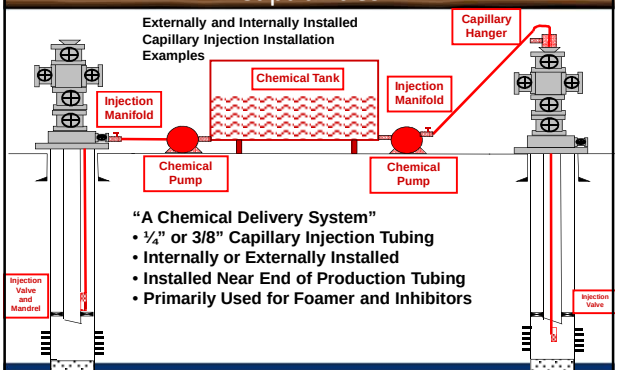
Capabilities

Externally and Internally Installed Capillary Injection Installation Examples



"A Chemical Delivery System"
- ¼" or 3/8" Capillary Injection Tubing
- Internally or Externally Installed
- Installed Near End of Production Tubing
- Primarily Used for Foamer and Inhibitors

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CAPILLARY COMPONENTS

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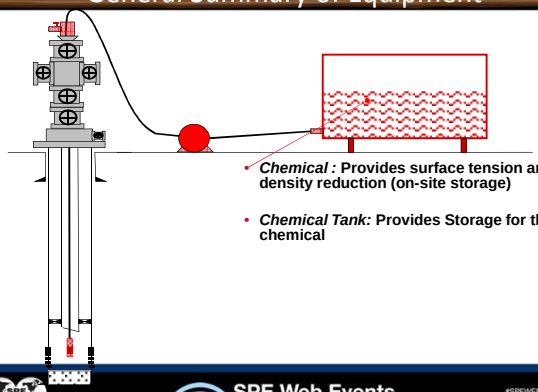
General Summary of Equipment



- ***Chemical :*** **Provides surface tension and density reduction (on-site storage)**
- ***Chemical Tank:*** **Provides Storage for the chemical**

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Chemical Tank

- The chemical tank is used for storage
- The tank lid is used as a filter so no particles or solids gets into the tank
- The manifold on the outlet of the tank has a filter that also helps prevent particles or solid from entering the cap string
- The chemical in the tank changes the density of the fluid

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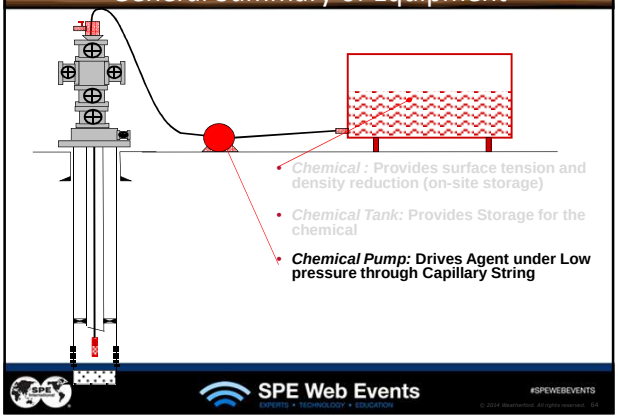
General Summary of Equipment



- *Chemical :* Provides surface tension and density reduction (on-site storage)
- *Chemical Tank:* Provides Storage for the chemical
- ***Chemical Pump:*** **Drives Agent under Low pressure through Capillary String**

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Chemical Pump

- The chemical pump is used to displace the chemical into the capillary string
- The pump is located between the chemical tank and capillary

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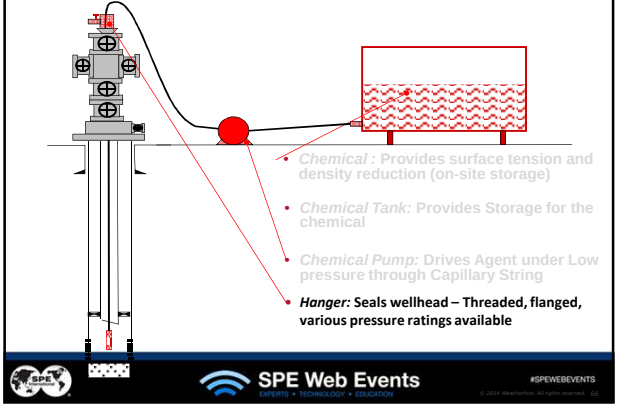
General Summary of Equipment



- *Chemical :* Provides surface tension and density reduction (on-site storage)
- *Chemical Tank:* Provides Storage for the chemical
- *Chemical Pump:* Drives Agent under Low pressure through Capillary String
- ***Hanger:*** **Seals wellhead – Threaded, flanged, various pressure ratings available**

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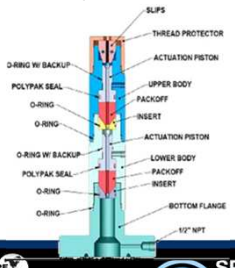
Capillary Injection Surface Hanger

- Threaded or Flanged Connections Available
- 3K, 5K, 10K, 15K PSI Ratings Avaialble
- Double Pack Off Options
- Lower BOP Assembly
- 2 3/8", 2 7/8" and 3 ½" EUE 8rd Threads Available
- Premium Alloy Materials for Harsh Environments(410 SS)



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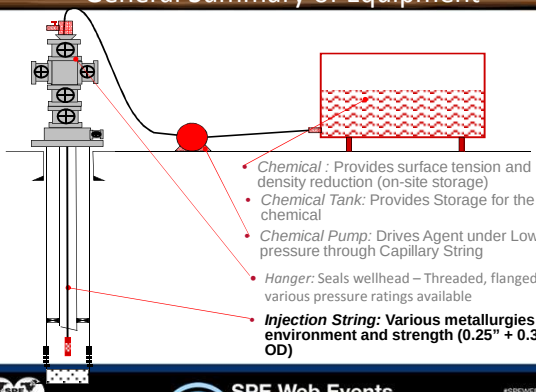

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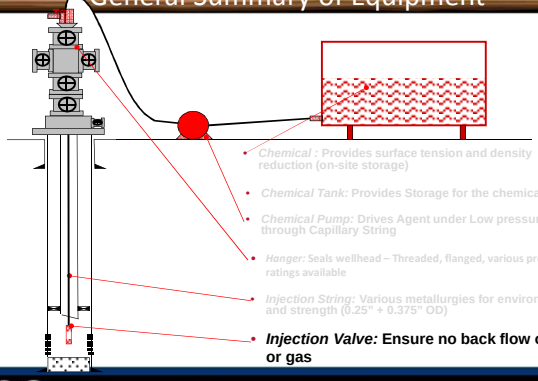
- *Hanger:* Seals wellhead – Threaded, flanged, various pressure ratings available
- ***Injection String:*** **Various metallurgies for environment and strength (0.25" + 0.375" OD)**

Injection String (Capillary)

- Capillary can come in several sizes, most common are 0.25" and 0.375"
- The capillary will stretch just like production tubing so that has to be considered when landing the BHA.

General Summary of Equipment



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- *Injection String:* Various metallurgies for environment and strength (0.25" + 0.375" OD)
- ***Injection Valve:*** **Ensure no back flow of fluid or gas**

Downhole Injection Valve CCI-1

- **Material**
  - **Monel Alloy Steel**
- **Dimensions**
  - **12" L X 1.0" O.D.**
- **Working Pressure**
  - **Maximum 8,400 psi Differential**
- **Temperature**
  - **450 Degrees F**

Purpose:

- **Prevents Chemical Siphoning**
- **Prevents Gas Back Flow**
- **Allows for Precise Chemical Injection**

Set Pressure Determined By:

- **Hydrostatic Weight of the Chemical in Capillary Tubing**
- **Flowing Bottomhole Pressure**
- **Injection Pump Pressure @ Surface**
- **Set By Hand On Location**

CAPILLARY CANDIDATES

Capillary and Chemical Applications

- Liquid Loading
- Corrosion Control
- Scale Control
- Salt Control
- Paraffin Control
- H_2S Control
- Combination Products

Capillary Injection is a Chemical Delivery System

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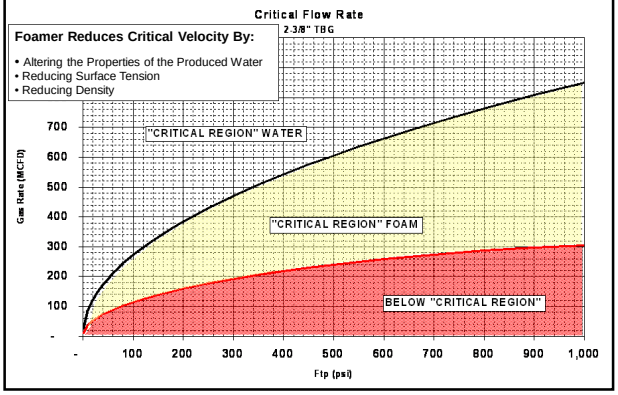
Foam Assisted Critical Flow Rates – +/- 2/3 Reduction



Corrosion & Metallurgy

Which metallurgy is appropriate?

Standard Metallurgies

Duplex 2205 (Low chlorides, low pH, Low temps)
Duplex 2507 (Low chlorides, low pH, Low temps)
Alloy 825 (higher chlorides, low pH, higher temps)
Alloy 625 (high chlorides, higher pH high temps)

- Considerations
  - Partial pressures of H_2S & CO_2
  - Chlorides, temperature, pH
  - Depth

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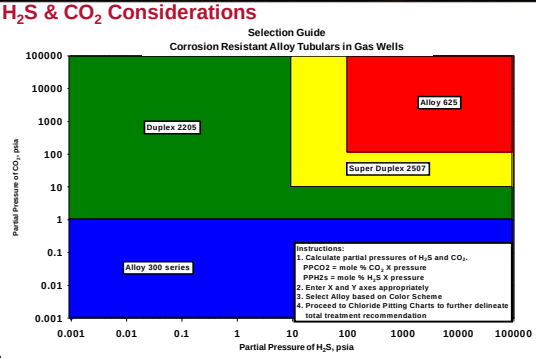
Capillary Coiled Tubing General Overview

Dimensions and Strengths - Capillary Coiled Tubing

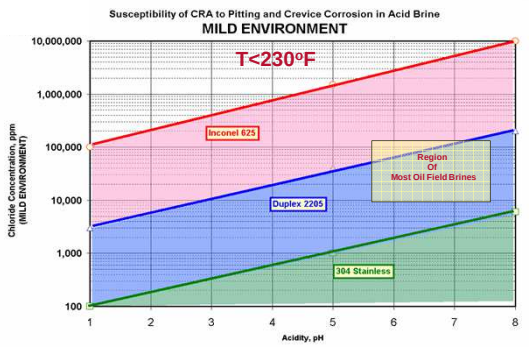
Property	Duplex 2205 Tubing	
	0.250" X 0.035"	0.375" X 0.049"
OD (inches)	0.250	0.375
WT (inches)	0.035	0.049
Weight (lbs/1000')	80.6	171.0
Capacity (gal/1,000 FT)	1.3225	3.1300
Tensile Strength (Mpsi)	120-125	120-125
Yield Strength (Mpsi)	90-100	90-100
Working Pressure (psi)	8,400	8,400
Burst Pressure (psi)	25,000	25,000
Collapse Pressure (psi)	23,500	23,500

Corrosion & Metallurgy

H_2S & CO_2 Considerations

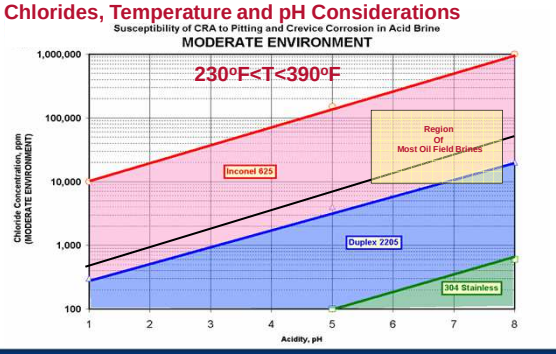


Corrosion & Metallurgy



Corrosion & Metallurgy

Chlorides, Temperature and pH Considerations



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AFTER INSTALLATION

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How Much Foamer Do I Need to Inject?

- Rules of Thumb:
  - 1 Gallon of Foamer per 40 bbls of Water (100% H2O)
  - Largely affected by:
    - Hydrocarbons
    - Solids
    - Temperatures
    - Concentration of Foamer
  - Example:
  - 100 bbls water per day = 2.5 gallons of foamer(100% H2O)
  - Optimize After Initial Clean Up
  - Remember that Oil is Natural De-Foamer
  - With Oil Present- Rule is 2 Gallons per 40 bbls
    - Rule of Thumb- 40% Oil Cuts or Lower for Good Candidate

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Chemical Optimization: *Foamer Selection Process*

What foamer/chemical is appropriate?

Considerations

- Water Volume
- Water Salinity/Hardness
- Liquid Hydrocarbon Content
- Temperature
- Bacteria
- Foam ½ Life
- OTHERS

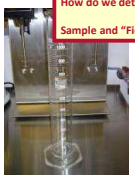
Field Chemical Test Process

Utilizing Actual Field Producing Liquids and Ratios…

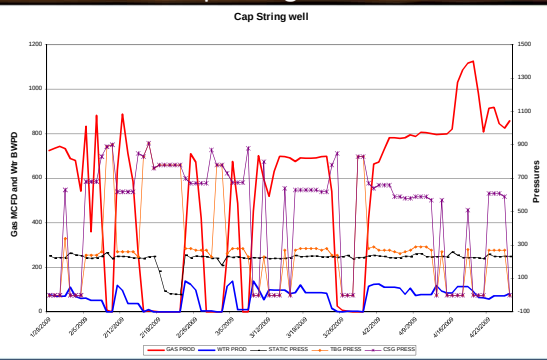
- **Foam qualities are measured utilizing the industry standard test method (high speed blenders)**
- **Foam Height vs. concentration**
- **Foam ¼ life vs. concentration**
- **Foam ½ life vs. concentration**
- **Observations are included (water vs. hydrocarbon ratios and emulsion tendencies)**

How do we determine the right chemical….

Sample and "Field" Test…



Cap String Well



MAINTENANCE

Capillary Preventative Maintenance

- Capillary Plugging Due to Particles or Solids
  - Tank Lid and Filter System in Place
- Maintain a Clean System at Well Site
  - Weatherford Injection Manifold
- Maintenance Schedule
  - Regular Filter Cleaning / Change Out
  - Regular Capillary Tubing Flush
- Good BHA
  - WFT CCI-1A

Capillary "Preventative Maintenance" Recommendations

- 1) Rig up unit, pull, inspect and flush cap string. Replace BHA, Redress packoff, Re-install string and rig down.
- 2) Rig up unit, pick cap string up 200 – 300 feet and reset. Flush string with water and reload with chemical. Rig down unit.

Capillary System "Chemical" Failures

Chemical Capillary Failures can be identified into three primary categories:

- Plugging due to Particles
- Chemical Polymerizations
- Operator Error

Solutions to Reduce Premature Capillary System Failures

- **Capillary Failure due to Operator Error**
  - Implement training - Standard Operating Procedures (SOP's) at the well site.
  - Selective metallurgy processes considering temperature, fluid and gases profiles.
  - Chemical Capillary well installation considerations (ie: depth and location where the capillary is set.
  - Wellhead equipment qualities that do not mark or pinch the capillary creating a weak point.
  - Capillary tubing splicing procedures – Review the welding procedure and certify the welder.

Ask the Audience

What can cause plugging inside a capillary injection string?

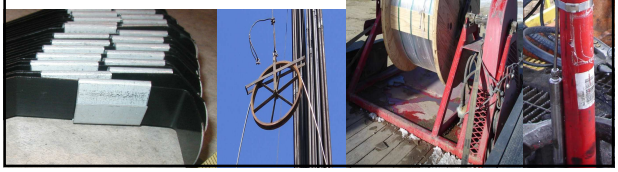
Externally Banded Capillary Injection Options

Applications Include:

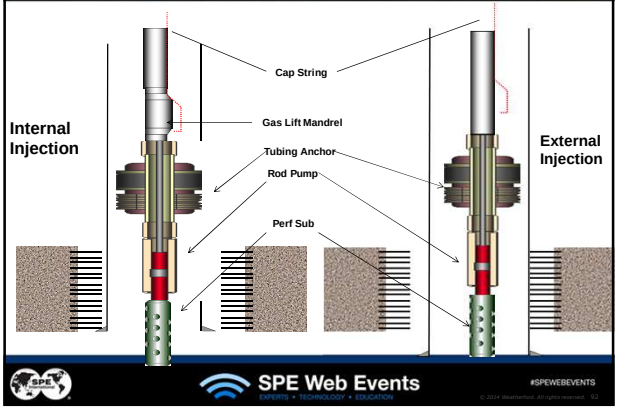
- Foamer Injection
- Scale Inhibitor
- Corrosion Inhibitor
- Fresh Water Salt Control
- Hydrate Control
- Sub Surface Safety Valve Installation
- Run Externally on Rod Pump Wells

Advantages Include:

- Swab Well In After Installation
- Can Run Plunger Lift
- Some Bands Reusable
- Can use with Most Lift Types



Externally Banded Capillary Treatment Methods



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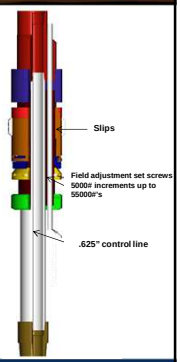
Injection Tubing Anchor

- Reciprocating Rod Pump Tubing Anchor (Anchor only)
- By-Pass Area for ¼" and 3/8" Capillary Injection Tubing
- Allows for Injection Point Below Tubing Anchor Near Pump (high and low fluid levels)
- Perfect for Extended Perforation Interval and Horizontal Completions
- Tubing and rod protection



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