Introduction to Plunger Lift

David Cosby, P.E.
Shale Tec LLC
Introduction to Plunger Lift

How does plunger lift work

Why is artificial lift required

When is plunger lift required

Applications and benefits

Installation and operation

Safety

Primary Purpose
Removal of liquid from gas wells so that gas can flow freely to the surface

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Denver, Colorado
HOW DOES PLUNGER LIFT WORK
How Does Plunger Lift Work

- Bottom Hole Spring
- Plunger
- Arrival Sensor
- Lubricator / Catcher
- Pressure Transducers
- Control Valve(s)
- Gas Flow Meter
- Well Head Controller
How Does Plunger Lift Work

LIQUID LOAD = (CP – TP)

LIFT PRESSURE = (CP - LP)

PLUNGER FALL VELOCITY
SPE 80891 – Determining how different plunger manufacturer features affect plunger fall velocity

FOSS and GAUL Required Pressure
SPE 120636 – Modified Foss and Gaul model accurately predicts plunger rise velocity

<table>
<thead>
<tr>
<th>Mode</th>
<th>Control Valve</th>
<th>Gas Flow</th>
<th>Plunger</th>
<th>Casing Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall (Gas)</td>
<td>CLOSED</td>
<td>NONE</td>
<td>FALLING</td>
<td>INCREASE</td>
</tr>
<tr>
<td>Fall (Liquid)</td>
<td>CLOSED</td>
<td>NONE</td>
<td>FALLING</td>
<td>INCREASE</td>
</tr>
<tr>
<td>Pressure Build</td>
<td>CLOSED</td>
<td>NONE</td>
<td>BOTTOM</td>
<td>INCREASE</td>
</tr>
<tr>
<td>Rise</td>
<td>CLOSED</td>
<td>FLOW</td>
<td>RISING</td>
<td>DECREASE</td>
</tr>
<tr>
<td>Production</td>
<td>OPEN</td>
<td>FLOW</td>
<td>SURFACE</td>
<td>DECREASE</td>
</tr>
</tbody>
</table>

Just before well opens
How Does Plunger Lift Work

Video courtesy of PCS Ferguson

Production Control Services (PCS) and Ferguson Beauregard are now PCS Ferguson

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WHY IS ARTIFICIAL LIFT REQUIRED
Why Is Artificial Lift Required

DECREASING GAS FLOW RATE

MIST FLOW

TRANSITION FLOW

SLUG FLOW

BUBBLE FLOW

LIQUID LOADED

Water Droplets

Liquid Slugs

Gas Bubbles

LIQUID LEVEL

NO GAS FLOW

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Why Is Artificial Lift Required

Video courtesy of PCS Ferguson

Production Control Services (PCS) and Ferguson Beauregard are now PCS Ferguson
Why Is Artificial Lift Required

LOW Backpressure

LOW FBHP

MOST Production

FLOWING BOTTOM HOLE PRESSURE

Line Pressure
Liquid
Scale / Paraffin
Chokes
Valve Trim Size
Orifice Plate
90 Degree Elbows

Why Is Artificial Lift Required

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Inflow Performance Relationship

Relationship between the flow rate and flowing pressure

\[ Q_{sc} = C \left( P_r^2 - P_{wf}^2 \right)^n \]

Why Is Artificial Lift Required

ABSOLUTE OPEN FLOW!
Why Is Artificial Lift Required

Inflow Performance Relationship (Vogel) Curve

Producing BHP = 265 Psi
Static BHP = 900 Psi
Oil Rate = 0 BPD
Water Rate = 10 BPD
Gas Rate = 380 Mscf/D
Qmax Gas = 435.9 Mscf/D

Reduction in PBHP = 90 Psi
Predicted Oil Rate = 0.0 BPD
Predicted Gas Rate = 10.7 BPD
Predicted Gas Rate = 405.8 Mscf/D
Production Increase = 6.8 %

Courtesy of EchoMeter
Why Is Artificial Lift Required

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PLUNGER LIFT
WELL
REQUIREMENTS
Plunger Lift Well Requirements

- **IS LIQUID IN THE TUBING?**
  - (Over 90% of US Gas Wells)
  - **YES**

- **IS GAS VOLUME SUFFICIENT?**
  - **YES**

- **IS GAS PRESSURE SUFFICIENT?**

  - **ERRATIC PRODUCTION**
  - **DECLINE CURVE ANALYSIS**
  - **CRITICAL FLOW RATE**

  - **400 SCF / BBL / 1,000 FT OF LIFT**
    - Foss and Gaul is a more precise predictor

  - **LIFT PRESSURE \( \geq 2 \times \) LIQUID LOAD**
    - Lift Pressure = \( CP - LP \); Liquid Load = \( CP - TP \)
Plunger Lift Well Requirements

**IS LIQUID IN THE TUBING?**

![Graphs showing production, casing pressure, line pressure, and plunger lift installed over time.](image-url)

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Plunger Lift Well Requirements

What’s happening at bottom of well?

Coleman Critical Flow Rate is 20% less than Turner

SPE 120625 “Guidelines for the Proper Application of Critical Velocity Calculations” by Sutton, Cox, Lea, Rowlan

SPE 94081 “A Systematic Approach to Predicting Liquid Loading in Gas Wells” by Gua, Ghalambor, Xu.
Plunger Lift Well Requirements

Video courtesy of Marathon

Liquid Loading
Unstable Slug Flow
2-in Tubing
Plunger Lift Well Requirements

**NO PACKER**
400 SCF / BBL / 1,000 FT OF LIFT

**Example:**
400 scf X 10 bbls X 7500 ft / 1000 ft
30,000 scf or 30 mcf

Compare actual gas volume to required gas volume – with clear tubing!

**IS GAS VOLUME SUFFICIENT?**

- More Gas/Liquid required
- Less Gas/Liquid required
- Add Gas as needed

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**LIFT PRESSURE**

Lift Pressure $\geq 2\times$ Liquid Load

**LOAD FACTOR**

Liquid Load / Lift Pressure $\leq 0.5$

**FOSS AND GAUL**

$CP_{req'd} = CP_{min} \times \left\{ (A_{ann} + A_{tbg}) / A_{ann} \right\}$

$CP_{min} = \{SLP + P_p + P_cFV\} \times \{1 + D/K\}$

$CP =$ Casing Pressure; $SLP =$ Sales Line Pressure

$A_{ann}$ = Area Annulus; $A_{tbg}$ = Area Tubing

$P_p =$ Pressure req’d to lift just the plunger

$P_c =$ Pressure req’d to lift 1 bbl of fluid and overcome friction

$FV =$ Fluid Volume above the Plunger

$K =$ Constant accounting for gas friction

$D =$ Depth of the Plunger

**IS GAS PRESSURE SUFFICIENT?**

- Packer ?
- No holes in tubing
- Same ID from BHS to Lubricator
- End of tubing location
- Control valve trim size
- Orifice plate trim size
- Flow meter properly sized
- Pipeline pressure surge restrictions
- Dump valves appropriate for surges
- Clean / dry gas supply available
- Knowledgeable operator(s) ! ! !

**OTHER CONSIDERATIONS**

**Tubing**

| 2 3/8  | 33,500 | 165 |
| 2 7/8  | 45,000 | 102 |
| 3      | 57,600 | 67  |
APPLICATIONS AND BENEFITS
Applications and Benefits

**TYPICAL APPLICATIONS**

**GAS WELLS**
- Removal of liquids
- Reduction of emissions
- Keeps tubing free of paraffin, salt & scale

**OIL WELLS**
- Produce from high GLR wells
- Conserve formation pressure
- Control paraffin and hydrates

**LOW GAS TO LIQUID RATIO WELLS**
- 2 Stage plunger lift
- Plunger assisted gas lift
- Gas assisted plunger lift

**TYPICAL BENEFITS**

**STABILIZES AND IMPROVES PRODUCTION**
- 20% improvement is common
- Keeps tubing clear of debris
- Can produce wells to depletion
- Produces with a low casing pressure

**ECONOMICAL**
- Low initial investment
- Low operating, repair and maintenance costs
- Reduces chemical cost, venting and swabbing
- Rig not required for installation
- Cost of system is unaffected by well depth

**GOOD FOR THE ENVIRONMENT**
- Reduces methane emissions and lost gas
- Operates on solar energy
Benefits with Telemetry

STABILIZE AND IMPROVE PRODUCTION
- Allows skilled operator to control many wells
- Optimize production using real time data and trends
- Rapid and enhanced troubleshooting accuracy

ECONOMICAL
- Identify & resolve problems before profits are lost
- Reduce windshield time
- Reduce equipment repair and maintenance
- Reduce unplanned well downtime

SAFETY
- Remote, real time knowledge of well site parameters
- Remote shut-in of wells when necessary
- Less drive time (fuel, insurance, maintenance)

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Economics

**COST ITEMS**
- Check tubing
  - Drift, broach, pressure check
- Set bottom hole spring
- Re-configure well head tree
- Install lubricator
- Install control (motor) valve
- Install pressure transducers

**COST ITEMS**
- Establish communication with flow meter and “office”
- Install plunger lift controller
- Route clean, dry gas to solenoid
- Install plunger
- Swab well if necessary
- Establish controller settings

**Maintain wells natural decline curve. Don’t wait till production is lost!**

<table>
<thead>
<tr>
<th>Flow Rate</th>
<th>10 % Change</th>
<th>15 % Change</th>
<th>20 % Change</th>
<th>25 % Change</th>
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<tbody>
<tr>
<td>100 Mcf/d</td>
<td>$1,200 / mo</td>
<td>$1,800 / mo</td>
<td>$2,400 / mo</td>
<td>$3,000 / mo</td>
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<tr>
<td>200 Mcf/d</td>
<td>$2,400 / mo</td>
<td>$3,600 / mo</td>
<td>$4,800 / mo</td>
<td>$6,000 / mo</td>
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<tr>
<td>300 Mcf/d</td>
<td>$3,600 / mo</td>
<td>$5,400 / mo</td>
<td>$7,200 / mo</td>
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<tr>
<td>400 Mcf/d</td>
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<td>500 Mcf/d</td>
<td>$6,000 / mo</td>
<td>$9,000 / mo</td>
<td>$12,000 / mo</td>
<td>$15,000 / mo</td>
</tr>
</tbody>
</table>

- $4 / mcf
INSTALLATION AND OPERATION CONSIDERATIONS
Installation Considerations

Minimize Restrictions!

- Scale, Paraffin – Drift and broach tubing
- Bottom hole spring holddown – size, debris
- Motor valve trim – full port opening
- Orifice plate at flow meter
- Well head – Sleeve if needed
- Chokes

Flow Area = \( \pi r^2 \)

<table>
<thead>
<tr>
<th>Diameter</th>
<th>Area</th>
<th>% Difference</th>
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<tbody>
<tr>
<td>7/8 inch</td>
<td>0.601 inch(^2)</td>
<td>0 %</td>
</tr>
<tr>
<td>1 inch</td>
<td>0.785 inch(^2)</td>
<td>30.6 %</td>
</tr>
<tr>
<td>1 ¼ inch</td>
<td>1.227 inch(^2)</td>
<td>104.2 %</td>
</tr>
<tr>
<td>1 ½ inch</td>
<td>1.767 inch(^2)</td>
<td>194.0 %</td>
</tr>
</tbody>
</table>
Installation Considerations

End of Tubing Location - Vertical Well

- Tubing too high
- Tubing too low or water column too high
- Tubing set correctly

- Liquid column pressuring lower zones
- Clear water column and restart plunger
- Tubing as low as possible and still surface plunger

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**Installation Considerations**

**Bottom Hole Spring Location – Horizontal Well**

<table>
<thead>
<tr>
<th>MD</th>
<th>TVD</th>
<th>EW</th>
<th>NS</th>
<th>DIP</th>
<th>AZM</th>
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<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<td>96</td>
<td>96</td>
<td>-0.33</td>
<td>-0.07</td>
<td>0.4</td>
<td>257.4</td>
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<tr>
<td>158</td>
<td>158</td>
<td>-0.88</td>
<td>-0.47</td>
<td>0.9</td>
<td>224.6</td>
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<tr>
<td>188</td>
<td>187.99</td>
<td>-1.1</td>
<td>-0.86</td>
<td>0.9</td>
<td>192.9</td>
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<tr>
<td>219</td>
<td>218.98</td>
<td>-1.08</td>
<td>-1.5</td>
<td>1.5</td>
<td>169.5</td>
</tr>
</tbody>
</table>

**Key Considerations:**
- What is the tubing ID?
- How is BHS attached to tubing?
- What is the seating nipple ID?
- What is the tubing deviation at the anchor point?
- Is a SV and pressure relief spring required?
- If vertical, where is the end of tubing relative to the perf’s?

**Bottom Hole Spring Location - Deviation**

45 to 50 degree typical

SPE 147225 – Analysis of Plunger Lift Applications in the Marcellus Shale

**Tubing Details:**
- 229 jts 2 3/8" 4.7 lb/ft, J-55, FBN tbg
- F Nipple @ 7432.9
- 1 jt 2 3/8" 4.7 lb/ft, J-55, FBN tbg
- Notched Collar w/ ceramic disk
- EOT @ 7465 ft.
Algorithm Selection

Plunger Fall
- Time for plunger to start falling or reach bottom of well

Pressure Build
- Open at minimum pressure required to surface plunger at desired velocity

Plunger Rise
- Time for plunger to surface

End Production
- Maximize production. Allow the desired liquid volume to enter tubing on every cycle

Operation Considerations

Time = set point
Tubing pressure = set point
Casing pressure = set point
Tubing / Casing = set point
Tubing – Line = set point
Casing – Line = set point
Casing - Line = Foss and Gaul
Load Factor = % of Foss and Gaul
Load Factor = Set point

Allowed Fall Time

Allowed Rise Time

Allowed Conditions

Layered Conditions

Auto Adjusting Algorithms

Load Factor = Liquid Load / Lift Pressure

Plunger Fall

Time for plunger to start falling or reach bottom of well

Pressure Build

Open at minimum pressure required to surface plunger at desired velocity

Plunger Rise

Time for plunger to surface

End Production

Maximize production. Allow the desired liquid volume to enter tubing on every cycle

Time
Tubing pressure
Casing pressure
Tubing / Casing
Tubing – Line
Casing – Line
Casing - Line
Load Factor

Load Factor = Liquid Load / Lift Pressure

Time = set point
Tubing pressure = set point
Casing pressure = set point
Tubing / Casing = set point
Tubing – Line = set point
Casing – Line = set point
Casing - Line = Foss and Gaul
Load Factor = % of Foss and Gaul
Load Factor = Set point

Auto Adjusting Algorithms

Load Factor = Liquid Load / Lift Pressure
## Operation Considerations

### Preventative Maintenance

**Method**
- Who? What? When? How to track?

**Typical “checks”**
- Plunger
  - When to replace? How do you know?
- Lubricator
  - Spring, catcher, connection to WH
- Bottom hole spring
  - Debris, spring, seal
- Motor valve
  - Trim, gas supply if utilized
- Battery / Solar panel
- Valves - grease
- Arrival sensor & cable – no misses!
- Tubing – no obstructions, no holes
- Flow meter calibration

### Other

**Organizational structure**
- In house optimizers?
- Field operator responsibilities?

**Training**
- Who? How often? Track learning!
- Basic plunger lift principles
- Plunger lift equipment
- Optimization of wells
- Troubleshooting
- Controller settings
- Problem solving process

**Initial well lineout**
- Who?

**Remote monitor and optimize**
- In house? 3rd Party?
SAFETY
Arrive safely!

- In 2011, more than 2 out of every 5 fatal workplace incidents were transportation accidents.

- Four **primary** causes of O&G related transportation accidents:
  - Ignoring the speed limit
  - Using a cell phone while driving
    - About 80% of people involved in traffic accidents are distracted
  - Not wearing a seat belt
    - 63% of people killed in traffic accidents were not wearing seat belts
  - Lack of rest
    - Tired drivers involved in 4,000 road crashes in Texas in 2010
Serious Injuries

- Pressure traps (hydrates, sand, scale)
- Lubricator cap off, pressure trap under plunger
- Open master valve, hammer unions not secure
- Installing well head with underrated equipment
- High plunger velocity – especially when venting to tanks
- Compressed lubricator springs
- Removing cap, cracking open control valve
- Pressure gauges are not always right
Linkedin Group

“Plunger Lifted Gas Wells”

ADDENDUM
Fluid Volume in Tubing (Barrels)

- \( FV = 0.002242 \times (CP-TP) \times (ID^2)/SG \)
- CP = Casing Pressure; TP = Tubing Pressure
- ID = Tubing Inner Diameter (inches)
- SG = Specific Gravity (1.0 for water)

Fluid Height in Tubing (Feet)

- \( FH = (CP-TP) / (0.433 \text{ psi/ft} \times SG) \)
- 0.433 psi/ft = Pressure gradient of water
- SG = Specific Gravity (1.0 for water)
- Typically, fluid column is 20% liquid, 80% gaseous liquid (foam). Divide results by 20% to obtain height of the gaseous liquid column
# Tubing Fluid Height and Volume

## 2 3/8” tubing (1.995” ID)

<table>
<thead>
<tr>
<th>CP-TP (psi)</th>
<th>Liquid Volume (bbls ; SG = 1)</th>
<th>Liquid Height (solid column)</th>
<th>Liquid Height (80% gaseous)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.089</td>
<td>23 ft</td>
<td>115 ft</td>
</tr>
<tr>
<td>20</td>
<td>0.178</td>
<td>46 ft</td>
<td>231 ft</td>
</tr>
<tr>
<td>30</td>
<td>0.268</td>
<td>69 ft</td>
<td>346 ft</td>
</tr>
<tr>
<td>40</td>
<td>0.357</td>
<td>92 ft</td>
<td>462 ft</td>
</tr>
<tr>
<td>50</td>
<td>0.446</td>
<td>115 ft</td>
<td>577 ft</td>
</tr>
<tr>
<td>60</td>
<td>0.535</td>
<td>138 ft</td>
<td>692 ft</td>
</tr>
<tr>
<td>70</td>
<td>0.625</td>
<td>161 ft</td>
<td>808 ft</td>
</tr>
<tr>
<td>80</td>
<td>0.714</td>
<td>185 ft</td>
<td>923 ft</td>
</tr>
<tr>
<td>90</td>
<td>0.803</td>
<td>208 ft</td>
<td>1039 ft</td>
</tr>
<tr>
<td>100</td>
<td>0.892</td>
<td>231 ft</td>
<td>1154 ft</td>
</tr>
<tr>
<td>125</td>
<td>1.115</td>
<td>288 ft</td>
<td>1443 ft</td>
</tr>
<tr>
<td>150</td>
<td>1.338</td>
<td>346 ft</td>
<td>1732 ft</td>
</tr>
<tr>
<td>175</td>
<td>1.562</td>
<td>404 ft</td>
<td>2020 ft</td>
</tr>
<tr>
<td>200</td>
<td>3.569</td>
<td>923 ft</td>
<td>4618 ft</td>
</tr>
</tbody>
</table>

## 2 7/8” tubing (2.441” ID)

<table>
<thead>
<tr>
<th>CP-TP (psi)</th>
<th>Liquid Volume (bbls ; SG = 1)</th>
<th>Liquid Height (solid column)</th>
<th>Liquid Height (80% gaseous)</th>
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</thead>
<tbody>
<tr>
<td>10</td>
<td>0.133</td>
<td>23 ft</td>
<td>115 ft</td>
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<tr>
<td>20</td>
<td>0.267</td>
<td>46 ft</td>
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<tr>
<td>30</td>
<td>0.400</td>
<td>69 ft</td>
<td>346 ft</td>
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<td>40</td>
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<td>1443 ft</td>
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<td>346 ft</td>
<td>1732 ft</td>
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<tr>
<td>175</td>
<td>2.338</td>
<td>404 ft</td>
<td>2020 ft</td>
</tr>
<tr>
<td>200</td>
<td>5.343</td>
<td>923 ft</td>
<td>4616 ft</td>
</tr>
</tbody>
</table>
Sufficient Gas Volume

- No Packer
  - 400 scf / bbl / 1000 ft of lift
- Packer
  - 2,000 scf / bbl / 1000 ft of lift

Sufficient Gas Pressure

- Casing Pressure at least 1.5 X line pressure
- Lift Pressure at least 2 X greater than fluid load
- See Foss and Gaul requirements
Foss and Gaul (CP Required to Lift Plunger)

- \( \text{CP}_{\text{req'd}} = \text{CP}_{\text{min}} \times \left( \frac{A_{\text{ann}} + A_{\text{tbg}}}{A_{\text{ann}}} \right) \)
- \( \text{CP}_{\text{min}} = \{ \text{SLP} + P_{p} + P_{c}FV \} \times \{ 1 + D/K \} \)

- \( \text{CP} = \text{Casing Pressure}; \ \text{SLP} = \text{Sales Line Pressure} \)
- \( A_{\text{ann}} = \text{Area Annulus}; \ A_{\text{tbg}} = \text{Area Tubing} \)
- \( P_{p} = \text{Pressure required to lift just the plunger} \)
- \( P_{c} = \text{Pressure Required to lift 1 bbl of fluid and overcome friction} \)
- \( FV = \text{Fluid Volume above the Plunger} \)
- \( K = \text{Constant accounting for gas friction below the plunger} \)
- \( D = \text{Depth of the Plunger} \)

<table>
<thead>
<tr>
<th>Tubing</th>
<th>K</th>
<th>Pc</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 3/8</td>
<td>33,500</td>
<td>165</td>
</tr>
<tr>
<td>2 7/8</td>
<td>45,000</td>
<td>102</td>
</tr>
<tr>
<td>3</td>
<td>57,600</td>
<td>67</td>
</tr>
</tbody>
</table>
Critical Flow Rate (Coleman, $P_f$ Less Than 1,000 psi)

- $CV_{\text{water}} = 4.434 \times \left[ \left( \frac{67 - 0.0031P_f}{(0.0031P_f)^{1/2}} \right)^{1/4} \right]$
- $CV_{\text{condensate}} = 3.369 \times \left[ \left( \frac{45 - 0.0031P_f}{(0.0031P_f)^{1/2}} \right)^{1/4} \right]$
- $FR = CV \times \pi \times \left( \frac{ID}{2} \right)^2 \times \left( \frac{1 \text{ ft}}{144 \text{ in}^2} \right) \times 86,400 \text{ sec/day}$
- $CV =$ Critical Velocity (ft/sec)
- $FR =$ Flow Rate (scf/d)
- $P_f =$ Flowing Pressure
- $ID =$ Tubing Inner Diameter

Turner ($P_f$ Greater Than 1,000 psi)

- Turner = Coleman + 20%
**Standard Cubic Foot**

\[
\text{SCF} = \text{ACF} \times \frac{P_f}{P_s} \times \frac{T_s}{T_f}
\]

- **SCF** = Standard Cubic Foot of gas
  - Volume of gas contained in 1 ft\(^3\) at 60\(^\circ\)F and 14.7 psi
- **ACF** = Actual or Measured Cubic Foot
- **P\(_f\)** = Flowing pressure (psi); **P\(_s\)** = 14.7 psi
- **T\(_f\)** = Flowing temperature (\(^\circ\)R)
- **T\(_s\)** = Standard temperature (516.67\(^\circ\)R)
- \(^\circ\)R = \(^\circ\)F + 459.67
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