Downhole Gas Separator Selection

Lynn Rowlan
Downhole gas separators can be divided into different types:

• Most efficient to set the pump below the gas entry zone. However, not possible in horizontal.

• If the gas separator is placed in or above the fluid entry zone, then for lower capacity wells a gas separator assembly should be used that consists of an outer barrel having ports at the top of the barrel with a dip tube extending from the pump inlet down into the outer barrel and opening below the ports.

• If a higher capacity gas separator is required, then the formation fluids must be diverted into the larger diameter casing annulus for gas separation.
Gas Separator Liquid Capacity is Based on the Following Principle:

GAS BUBBLES FLOW UPWARD IN OIL OR WATER AT A RATE OF APPROXIMATELY 6 INCHES PER SECOND. THUS, GAS BUBBLES WILL BE RELEASED FROM A LIQUID COLUMN IF THE DOWNWARD LIQUID VELOCITY IS LESS THAN 6 INCHES PER SECOND.

A LIQUID COLUMN HAVING AN AREA OF 1 SQUARE INCH TRAVELLING AT 6 INCHES PER SECOND IS A RATE OF 50 BPD.

The outer pipe can be the casing or the outer barrel of a gas separator. The inner tube is the inlet to the pump.
The most efficient downhole gas separators locate the pump intake below the lowest gas entry point.

Gas is not pulled down to the pump perforations unless the liquid velocity is greater than 6 inches per second.
### Natural Gas Separator

#### Gas Separator Capacity – Pump Below Fluid Entry Zone

<table>
<thead>
<tr>
<th>Casing Size Inch</th>
<th>Dip Tube Size Inch</th>
<th>Description</th>
<th>Annulus Area* Sq Inch</th>
<th>Liquid Capacity BLPD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>3 1/2</td>
<td>Perforated Tubing Sub</td>
<td>23.1</td>
<td>1150</td>
</tr>
<tr>
<td>7</td>
<td>2 7/8</td>
<td>Perforated Tubing Sub</td>
<td>26.7</td>
<td>1335</td>
</tr>
<tr>
<td>7</td>
<td>2 3/8</td>
<td>Perforated Tubing Sub</td>
<td>28.8</td>
<td>1440</td>
</tr>
<tr>
<td>5 1/2</td>
<td>2 7/8</td>
<td>Perforated Tubing Sub</td>
<td>12.7</td>
<td>635</td>
</tr>
<tr>
<td>5 1/2</td>
<td>2 3/8</td>
<td>Perforated Tubing Sub</td>
<td>14.8</td>
<td>740</td>
</tr>
<tr>
<td>4 1/2</td>
<td>2 7/8</td>
<td>Perforated Tubing Sub</td>
<td>6.1</td>
<td>305</td>
</tr>
<tr>
<td>4 1/2</td>
<td>2 3/8</td>
<td></td>
<td>8.2</td>
<td>410</td>
</tr>
</tbody>
</table>

**Higher Capacity if Needed**

<table>
<thead>
<tr>
<th>Casing Size Inch</th>
<th>Dip Tube Size Inch</th>
<th>Description</th>
<th>Annulus Area* Sq Inch</th>
<th>Liquid Capacity BLPD</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 1/2</td>
<td>1 1/2</td>
<td>Perforated Line Pipe</td>
<td>16.4</td>
<td>820</td>
</tr>
<tr>
<td>4 1/2</td>
<td>1 1/4</td>
<td>Perforated Line Pipe</td>
<td>10.4</td>
<td>520</td>
</tr>
</tbody>
</table>

*Annulus Area Between Casing and Perforated Tubing Sub (or Line Pipe)
Gravity separation is the governing principle for downhole gas separators.

Downward Liquid velocity greater than 6 inches per second in separator pulls gas into pump.

Separator has less capacity than Natural Gas Separator that used the full Casing ID.
Most Common Gas Separator

“Poor Boy”

Generally assembled in the field using available materials:

• Perforated 4 ft pup joint
• 1 inch diameter dip tube
• 30 ft Mud Anchor
• Bull Plug
Modified “Poor Boy” Gas Separator

- Larger Collars
- Short strainer nipple
- Larger perforated tube
- Rough or small ports
- Long Dip Tube
- Larger Collars
- Joints of Tubing

Tubing Collars prevent perforated sub from laying against casing wall where liquid accumulates.
## "Poor Boy" Gas Separator

**Liquid Capacity**

### GAS SEPARATOR CAPACITY TABLE

<table>
<thead>
<tr>
<th>Outer Barrel Description and Size, Inch</th>
<th>Dip Tube Size Inch</th>
<th>Annulus Area SQ Inch</th>
<th>Liquid Capacity BPD</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 1/2 Perforated Tubing Sub</td>
<td>1.250</td>
<td>4.87</td>
<td>260</td>
</tr>
<tr>
<td>2 7/8 Perforated Tubing Sub</td>
<td>1.000</td>
<td>3.32</td>
<td>177</td>
</tr>
<tr>
<td>2 7/8 Perforated Tubing Sub</td>
<td>1.250</td>
<td>2.52</td>
<td>134</td>
</tr>
<tr>
<td>2 3/8 Perforated Tubing Sub</td>
<td>0.750</td>
<td>2.26</td>
<td>121</td>
</tr>
<tr>
<td>2 3/8 Perforated Tubing Sub</td>
<td>1.000</td>
<td>1.77</td>
<td>94</td>
</tr>
<tr>
<td>2 3/8 Perforated Tubing Sub</td>
<td>1.250</td>
<td>0.96</td>
<td>51</td>
</tr>
<tr>
<td>2 3/8 Perf Tub Sub &amp; 1.5&quot; Pump</td>
<td>1.760</td>
<td>0.69</td>
<td>37</td>
</tr>
</tbody>
</table>
Collar Size Separator Eliminates Poor Boy Deficiencies

A good separator must balance annular flow area, separator flow area, dip tube diameter and pressure drop.

Outer barrel OD same as collar OD.

Thin short wall outer barrel and short dip tube.

Large inlet ports distributed around outer barrel facilitate entry of liquid.
Eccentric Separator

LIQUID tends to accumulate where the separator outer barrel touches the casing.

GAS tends to flow up the wide side of the casing annulus.

Tubing anchor should be at least 3 joints above separator to allow separator to fall against casing.
Laboratory Testing of Gas Separators

- Tubing
- Casing Perforations
- Separator Inlet Slots
- Dip Tube
- Separator Tube
- Casing
Effect of Liquid Velocity

Separator dip tube

5 inch/sec
243 BPD

6 inch/sec
275 BPD

9 inch/sec
420 BPD
243 BPD ~ 5 inch/sec flowing in the 6 inch by 3 inch annulus.
109 MCF/D gas. Dip tube is 1.5 inch diameter.
275 BPD ~ 6 inch/sec flowing in the 6 inch by 3 inch annulus. 109 MCF/D gas. Dip tube is 1.5 inch diameter.
420 BPD ~ 9 inch/sec flowing in the 6 inch by 3 inch annulus. 109 MCF/D gas. Dip tube is 1.5 inch diameter.
Casing Pressure Buildup
.25 psi/min ~ 18 Mscf/D
Annular Gas Flow Rate
Collar Sized Gas Separator Franks #1

**Production of 100 BPD with a Full Pump**

Casing Pressure Buildup:
- 1.8 psi/min
- 1.00 min

Casing Pressure Buildup:
- 1.8 psi
- 1.00 min

Annular Gas Flow Rate:
- 161 Mscf/D

**June 3 – 5, 2013**

2013 Appalachian Basin Gas Well Deliquification Workshop, Marietta, Ohio
Liquid Moves Slower in Separator Annulus Than Inside Pump Chamber

- **1.8 sec SV Opens**
- **4.17 sec SV Closes**

Average Liquid Velocity Inside Separator = -1.9 in/sec

Liquid Velocity Inside Separator

Elapsed Time - Seconds
During 5th Stroke 1 in/sec Bubble is Pulled into Bottom of the Dip Tube

- Plunger Dia. 1.25 Inch
- Plunger Area 1.227 sq.in.
- Pump Depth 10,540 feet

- 2 3/8” Collar Sized Gas Separator
- Area between Dip Tube and Barrel
- ID - OD 4.581 sq.in.

Elapsed Time - Seconds

Position - Inches

Begin 0 - SV Opens 1.8 - SV Closes 4.17 – End 8.633 sec.

6.95 SPM
GAS Should NOT Flow Too Fast Past Outside Gas Separator

MIST FLOW

Gas Velocity should be less than 10 ft/sec in Annulus Between ID of Casing and OD of Gas Separator

FREE GAS BUBBLES MOVE UPWARD THROUGH THE OIL THAT REMAINS IN THE CASING ANNULUS AND THE ACCUMULATION OF OIL IN THE CASING ANNULUS CAUSES REDUCED FLOW FROM THE FORMATION

MIST FLOW
HIGH GAS FLOW RATES EXCEEDING 10 FEET/SEC IN THE REDUCED AREA BETWEEN THE CASING AND THE OVERSIZE GAS SEPARATOR CAUSE THE LIQUID TO BREAK INTO SMALL DROPLETS THAT ARE CARRIED WITH THE GAS. THE LIQUID DOES NOT FLOW INTO THE GAS SEPARATOR

HIGHER BOTTOMHOLE PRESSURES REDUCE THE GAS FLOW VELOCITY
To get gas capacity of a specific installation multiply the table value by the Pressure at the Pump Intake (psi) and divide by 14.7

<table>
<thead>
<tr>
<th>Tubing Size Inches</th>
<th>Collar O.D. Inches</th>
<th>Liquid Capacity Bbl/Day</th>
<th>Gas Capacity MCF/D @ 1 Atm of Pump Intake Pressure *</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 3/8</td>
<td>3.0</td>
<td>229</td>
<td>35</td>
</tr>
<tr>
<td>2 7/8</td>
<td>3.75</td>
<td>413</td>
<td>11</td>
</tr>
<tr>
<td>3 1/2</td>
<td>4.5</td>
<td>624</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>5.0</td>
<td>778</td>
<td>-</td>
</tr>
<tr>
<td>4 1/2</td>
<td>5.6</td>
<td>1016</td>
<td>-</td>
</tr>
</tbody>
</table>

* Multiply Gas Capacity times Pump Intake Pressure in Units of Atms.
Packer Gas Separator

- Uses gravity separation like the “Poor Boy” except much more separation area and capacity.

- Higher cost and higher risk of mechanical and sand problems.

- Page Oil Tools 1957
Wolfberry Packer Type Separators Performance

% Liquid in Gaseous Liquid Column Vs. % Pump Fillage

Gas Separator Ineffective

Gas Separator Effective

% liquid in Gaseous Liquid Column Vs. % Pump Fillage
Fluids from the formation flow upward to the gas separator and then flow through a concentric annulus to an outlet at the top of the separator which discharges on one side into the casing annulus.

The gas rises and the liquid falls in the casing annulus.

The pump inlet is located at the bottom of the gas separator causing the pressure drop from the liquid at the bottom of the separator to the pump inlet to be negligible.

Diverter Cups or a packer or tail pipe with packer is located below the Separator to force formation fluids into the separator.
Top Collar

Inner and Outer barrels

Larger Outer barrel over seating nipple

Seating Nipple, conventional or mechanical

Two Large Holes for liquid flow into pump inlet

Lower Collar and mating assembly
Dynamometer and Acoustic Analysis of Seating Nipple Type Gas Separator Performance

Casing Pressure Buildup:
- 4.13 psi/min ~ 298 Mscf/D
- Annular Gas Flow Rate

Gas Separator with Seating Nipple

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Diverter Cup Assembly

Upper Male connection

8 Diverter Cups

Cups are loose fit to freely slide on mandrel

Low Pressure Packer Replacement

Lower Male Connection
Packer-Type Separator Configurations

- All of the formation fluid must be directed into the bottom of the separator to pass through the separator and be discharged out of the top of the separator. Then the discharged liquid in the casing annulus falls to the pump inlet and the gas flows upward.

- Flow can be directed through the separator using:
  1. Packer
  2. Diverter Cups
  3. Tail Pipe with packer

- All installations must have one of the diverter devices to force the formation fluids upward through the separator and out of the top of the separator.
Tail Pipe With Packer or Stinger Reduces Producing Bottom Hole Pressure

**Graph:**

- **Title:** Vogel - Tubing Capacity Curves w/ PIP @ 100 Psia - 3000 ft Tail pipe
- **Axes:**
  - Y-axis: Bottomhole Pressure - Psia
  - X-axis: Flow Rate - STBPD
- **Legend:**
  - 3000 SPHP
  - 2000 SBHP
  - 1000 SBHP
  - Tubing 1.995” ID
  - Tubing 5.015” ID

Graph shows the relationship between flow rate and bottomhole pressure for different tubing capacities and sizes.
Determine Gaseous Liquid Column Gradient Below Liquid Level

Adjusted Liquid Level

\[ D_a = D_L + (1 - f_o) L \]

- \( D_a \): adjusted depth to liquid level, ft
- \( D_L \): depth to top of liquid, ft
- \( f_o \): effective oil fraction
- \( L \): length of gaseous liquid column, ft

Transition from Collar Sized to Packer Type Gas Separator

If Liquid Rate is Low, Poor Boy Gas Separator May be OK
# Downhole Gas Separator Selection Criteria

<table>
<thead>
<tr>
<th>Casing Size inches</th>
<th>Downhole Gas Separator Type</th>
<th>Pump Displacement or Production Rate BPD</th>
<th>Casing Pressure Buildup Rate psi/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 1/2</td>
<td>2 3/8 Collar Sized (3.0&quot; OD)</td>
<td>&lt;200</td>
<td>any</td>
</tr>
<tr>
<td>5 1/2</td>
<td>2 3/8 Collar Sized (3.0&quot; OD)</td>
<td>&lt;200</td>
<td>&lt;2 psi/min</td>
</tr>
<tr>
<td>5 1/2</td>
<td>2 7/8 Collar Sized (3.75&quot; OD)</td>
<td>&lt;400</td>
<td>&lt;2 psi/min</td>
</tr>
<tr>
<td>5 1/2</td>
<td>3 1/2 Collar Sized (4.5&quot; OD)</td>
<td>&lt;600</td>
<td>&lt;2 psi/min</td>
</tr>
<tr>
<td>5 1/2</td>
<td>Seating Nipple Separator</td>
<td>&gt;50</td>
<td>&gt;2 psi/min</td>
</tr>
<tr>
<td>7</td>
<td>2 3/8 Collar Sized (3.0&quot; OD)</td>
<td>&lt;200</td>
<td>&lt;2 psi/min</td>
</tr>
<tr>
<td>7</td>
<td>2 7/8 Collar Sized (3.75&quot; OD)</td>
<td>&lt;400</td>
<td>&lt;2 psi/min</td>
</tr>
<tr>
<td>7</td>
<td>3 1/2 Collar Sized (4.5&quot; OD)</td>
<td>&lt;600</td>
<td>&lt;2 psi/min</td>
</tr>
<tr>
<td>7</td>
<td>Seating Nipple Separator</td>
<td>&gt;100</td>
<td>&gt;2 psi/min</td>
</tr>
</tbody>
</table>
Conclusions

• Best gas separation efficiency by locating pump intake below gas entry point.
• Improved efficiency by maximizing flow areas for gravity separation.
• Gas flow on the high side of annulus due to Decentralization improves efficiency
• Proper separator selection takes into account gas production rate and pump liquid capacity.
• Use casing pressure buildup rate to help select Gas Separator Type.
• Use %Liquid Surrounding Separator with %Pump Fillage to Determine Separator Performance
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