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1.0 LPG Vantage Frac Flow Back Guide

Material Safety Data Sheets (MSDS) for the LPG Fracturing Fluids must be on location and reviewed.

This document provides a very general guide to assist the well operator to safely and efficiently recover LPG following a fracture treatment. LPG flow behavior properties are provided along with recommendations for equipment sizing, procedure and potential hazards. Reference the Enform document, Well Testing and Fluid Handling, Industry Recommended Practice (IRP), Volume 4 – 2009, for all practices relating to flow back and fluid handling.

Section 4, 3, 7, 1 - Recovering Flammable High Reid Vapor Fracturing Fluids. Note: High RVP fracturing fluids include propane, butane, isobutene, etc. http://www.enform.ca/media/3672/irp4_final-2009.pdf

The LPG utilized is typically HD5 propane containing greater than 90% propane. In some cases the HD5 propane is mixed with commercial grade butane at varying quantities. All considerations provided in this flow back guide are relevant to propane-butane mixes; however the recommended separator operating conditions will differ with butane content. Note that the terms LPG and propane are used interchangeably within this text, however unless specifically identified otherwise, all information is relevant to propane.

Suitable procedures and tankage need to be in place where hydrocarbon liquids such as formation oil, condensates or oil based workover fluids are to be recovered during flow back. In particular, always ensure that high vapor pressure hydrocarbons are not placed into atmospheric tanks.
2.0 Flow Back Equipment – Closed System

Figure 1 displays a simple schematic for a closed system flow back configuration. A closed system is recommended for all LPG frac flow backs. Actual equipment and configuration used is left to the operator as it must be based upon the specific conditions and requirements for any given application. Provide, rig-in and operate all equipment within the recommendations and practices of Well Testing and Fluid Handling, Industry Recommended Practice (IRP), Volume 4 – 2009.

When specifying the requirements of flow back equipment for the Fracturing Process and recovery of LPG consider the following:

2.1 A safety program and documented site specific job safety plan for the LPG flow back process. Within the documented site specific safety plan; Identify ignition sources (vaporizer, line heater, engines, light towers, flare, etc) and appropriate controls are in place to mitigate ignition sources in the event of a release. A growing acceptance of the “Flare out Suppression System” has been used to mitigate the ignition sources of flare, vaporizer and line heater. Please see associated Safety Services Recommendations, section 9.

Identify and communicate that “At no time should high vapor pressure hydrocarbon returns, including LPG, be directed to the atmosphere or non-pressure tanks.”

2.2 An Emergency Shutdown Valve meets or exceeds the wellhead design on the well head.

2.3 Placement of the Choke before the line heater, prior to the last or secondary separator, should be considered. The LPG cools with pressure drop due to vaporization which improves line heater efficiency.

2.4 The Liner Heater is used to heat returns as required to maintain the separator temperature within the gas region. Capacity requirements are presented in Section 5.0 of this document.

2.5 Separators with steam coils may be considered in the event LPG liquids do accumulate. In the last or secondary separator, maintain operating conditions within vapor region, Section 3.0 of this document, to avoid LPG accumulation.

2.6 Fluid from the last or secondary separator must be handled in one of the following ways:
   - Produced to a pressurized storage vessel with minimum working pressure of 1,379Kpa for recovery conservation
   - Diverted to pipeline
   - Vaporized to flare

2.7 Collect ALL liquids to a Pressure Tank vented to the flare. LPG may be dissolved into or entrained within collected liquids. Ensure all liquids are stabilized prior to shipping or handling. “At no time should high vapor pressure hydrocarbon returns, including LPG, be directed to the atmosphere or non-pressure tanks.”

2.8 Flare stack with a minimum height 18.3 m, 154 mm OD, this will allow for a maximum of rate of 27 EM3/day of propane to flared. Taller flares and larger flare maybe dictated by expected well performance.
Configuration for dry gas without anticipation of sand production. The Separator is operated at a temperature and pressure below the LPG saturation curve to allow the LPG to vaporize.
Equipment configuration for oil and liquid production with a contingency for sand production. Primary Separator used to remove sand production and is typically operated above the LPG saturation temperature and pressure to avoid cooling issues. Secondary Separator is operated at a temperature and pressure below the LPG saturation curve to allow the LPG to vaporize LPG / stabilize oil prior to transferring the oil to the Pressurized Storage Tanks.
3.0 Initiating Flow and Wellbore Fluid Recovery

Initial recovery of the propane, certainly that in the wellbore, is likely to be comprised of mostly liquid propane. The intent is to flow back this liquid propane at a rate of approximately 2 m$^3$ liquid/hr. It is important to recognize that unless liquid propane is to be recovered to a pressurized vessel, it typically needs to be vaporized. Vaporizing propane requires considerable heat; a line heater is required to permit vaporization.

Note that the liquid propane flow needs to be brought on slowly to ensure test equipment operation is stabilized before increased flows are attempted. Particular attention needs to be paid to the separator temperatures and pressures to avoid cooling of flow equipment, potential freezing, LPG build-up in the separator and ultimately liquid LPG delivery from the separator.

Consider the following:

3.1 Initiate liquid recovery through a variable choke at a low choke opening. Initial choke opening is dependent upon wellhead pressure and test equipment configuration and is left to the judgment of the operator. If unsure, a smaller choke opening will ensure controlled recovery through the test equipment. Flow rates can be adjusted as equipment operating conditions stabilize and the clean up proceeds.

3.2 Vaporization of any LPG liquid, including propane, requires considerable heat or energy. A line heater is needed for vaporization when recovering LPG liquids. Typically a 2MMBtu/hr line heater is used. Over specifying the needed capacity of the line heater is strongly recommended in order to ensure quick and efficient recovery. If too little heat is added prior to vaporization, the separator temperature will drop significantly and LPG liquids will accumulate. This will potentially allow liquids to the flare stack. Also, once liquids are accumulated within the separator, vaporization in separators is slow and the recovery period unnecessarily extended. As recovery proceeds, increasing quantities of reservoir fluids will be mixed with the LPG and the heat load needed for LPG vaporization will typically decrease.

3.3 Ensure the last or secondary separator vessel pressures and temperatures are maintained well within the gas region. Separator conditions within the liquid region will result in liquid propane accumulation in the separator. Always avoid conditions that will result in propane liquids within the separator. Reference Propane Saturation Graph, Attachment I.

Example 1:
The separator is operating at a temperature of 5°C and 700 kPa. Will propane liquid accumulate in the separator?

Answer:
On the horizontal axis of the Propane Saturation Chart, find the 5°C line. Move vertically along that line until it intersects the 700 kPa line.

The intersection point is above the saturation line so that propane liquid will accumulate within the separator. Consider increasing the temperature of the flow entering the separator to at least 25°C. Note that simply lowering the pressure in the separator will normally result in further cooling and not prove effective.
3.4 Example 2:
The separator is operating at a temperature of 35°C and 800 kPa. Will propane liquid accumulate in the separator?

Answer:
On the horizontal axis of the Propane Saturation Chart, find the 35°C line. Move vertically along that line until it intersects the 800 kPa line.

The intersection point is below the saturation line so that only propane gas will exist in the separator.

3.5 Manage pressure of the flow stream before and within the line heater. Placement of the choke at the wellhead may help flow conditions to stabilize prior to entering the line heater. Pressure drops after the line heater often result in vaporization with significant cooling and lower temperatures within the separator. Liquid propane accumulation may result.

3.6 In order to prevent freezing of accumulated water always operate the separator above 0°C.
3.7 If hydrocarbon liquids are naturally produced by the reservoir, condensate or oil, ensure all liquids recovered from the separator are held in tanks suitable for the composition. Reference Well Testing and Fluid Handling, Industry Recommended Practice (IRP), Volume 4 – 2009. Pressurized tanks or a closed system should be used for flow backs, storing, producing, pumping, swabbing or killing wells with high vapor pressure hydrocarbons.
4.0  **Calculating LPG Recovery**

Estimating the recovered LPG is a simple process. Most often, LPG will be recovered as a vapor or gas recorded through the separator meter run.

In general the recovered LPG is determined as follows:

4.1  Gas flow from the separator is measured as usual with volume of gas flow recorded.

4.2  The content of LPG in the flow is determined through either gas chromatograph analysis or by gas density.

4.3  Based on LPG content of the volume of gas flow, the amount of LPG vapor is determined.

4.4  One cubic meter (1 m$^3$) of LPG liquid when vaporized creates 272 m$^3$ of gas.

4.5  The LPG vapor quantity determined in 4.3 above is converted to a liquid quantity by dividing that number by the expected gas generated from the LPG at 272 m$^3$/m$^3$ liquid (0.272 10$^3$ m$^3$/m$^3$ liquid).

4.6  The LPG liquid recovery for 4.5 above is then recorded and tracked as with any liquid to determine the load fluid recovery.

4.7  Should LPG also be recovered as a liquid in a pressurized tank, then the calculated liquid volume from 4.6 above is added to the tank recovery volume to determine total volume recovered.

Example:

1.  A frac is completed using 100 m$^3$ of LPG. When totally vaporized the 100 m$^3$ of LPG will generate a volume of 27,200 m$^3$ (27.20 10$^3$ m$^3$) vapor or gas. If all LPG is vaporized, a cumulative LPG vapor recovery of 27,200 m$^3$ (27.20 10$^3$ m$^3$) will indicate complete recovery.

2.  Presuming 15 minute readings with a gas flow meter rate, Gas Rate, of 30,000 m$^3$/day (30.0 10$^3$ m$^3$/day), the gas volume for the 15 minute period is then determined at 312 m$^3$ (0.312 10$^3$ m$^3$).

\[
\text{Gas Vol} = (30.0 \times 10^3 \text{m}^3/\text{day}) \times (15 \text{ min} / 1440 \text{ min}/\text{day}) \\
= 312 \text{ m}^3 \text{ or } 0.312 \times 10^3 \text{ m}^3
\]

3.  Volumetric proportion of LPG in the flow stream is then determined at 78% over the time interval. The resulting recovery of LPG gas for the period is then 78% of the 312 m$^3$ (0.312 10$^3$ m$^3$) or 243 m$^3$ (0.243 10$^3$ m$^3$).

\[
\text{LPG Gas Vol} = 312 \times 0.78 \\
= 243 \text{ m}^3 \text{ or } 0.243 \times 10^3 \text{ m}^3
\]

Note: Proportion of the LPG in the flow stream can be very precisely determined by a gas chromatograph or reasonably estimated on a dry gas well by measuring the gas gravity.
4. Recognizing that each cubic meter of LPG liquid generates 272m$^3$ (0.272 $10^3$m$^3$) LPG gas, the recovered LPG liquid volume for that time period is then determined at 0.89m$^3$.

\[
\text{LPG Liq Vol} = \frac{243 \text{ m}^3 \text{ vapor}}{272 \text{ m}^3 \text{ vapor/m}^3 \text{ liquid}} = 0.893 \text{ m}^3
\]
5.0 **Heat Requirement for LPG Vaporization**

Heat for vaporization of the LPG is provided by the line heater. Additional capacity is recommended to account for variations in wellhead flowing temperature, flow rates, general heat losses and equipment inefficiencies.

Consider the following:

5.1 Minimum heat requirement is based on the expected LPG recovery rate and heat needed to vaporize.

5.2 Initial propane flow back at 2 m³ per hour is recommended, however much higher flow back rates are applied in some instances to minimize flow back time. Accelerating flow back requires a line heater that is properly sized for the anticipated recovery rates in order to ensure complete vaporization of the LPG at all times.

5.3 Shutting in the well for 48 hours or more after the fracture treatment typically allows for significant mixing of the LPG with reservoir fluids. In gas reservoirs, the mixing of natural gas with LPG within the reservoir will reduce the heat requirement for vaporization. The degree of mixing achieved in the wellbore itself is difficult to predict and liquid LPG recovery from the wellbore should be anticipated.

5.4 Over specifying the needed capacity of the line heater is strongly recommended in order to ensure quick and efficient recovery. If too little heat is available the separator temperature will drop significantly and LPG liquids will accumulate. This will potentially allow liquids to the flare stack. Also, once liquids are within the separator, vaporization can be slow and the recovery period unnecessarily extended. Always avoid accumulation of LPG liquids in the separator.

5.5 As recovery proceeds, increasing quantities of reservoir gas will be recovered decreasing the heat load needed for vaporization.

Example:

At a flow back wellhead temperature of 10°C and a liquid recovery rate of 2m³/hour, the minimum heat requirement for vaporization is determined as below.

1. Determine the energy (heat of vaporization) required to vaporize one cubic meter of propane at 10°C from Attachment II, Propane – Heat of Vaporization Volume Basis.

   Enter the horizontal axis of the Propane – Heat of Vaporization chart, find the 10°C line. Move vertically along the 10°C line until it intersects the heat of vaporization curve. At the intersection move horizontally to the axis and read the value at 185,000 kJ/m³.

2. With a presumed flow back rate of 2m³/hour, the heat required is 370,000kJ/hr (103kWh, 0.35 MMBtu/hr)

   \[
   \text{Heat Req'd} = 2\text{m}^3/\text{hour} \times 185,000 \text{ kJ/m}^3 \\
   = 370,000 \text{ kJ/hour} \times 0.000278 \text{ kW/kJ/hour} \\
   = 102.786 \text{ kWh, or}
   \]
= 370,000 kJ/hour x 0.94782 Btu/hour/kJ/hour
= 350 Btu/hr or 0.35 MMBtu/hr

3. Presuming recovery rates as high as 5m³/hour may be desired and the well head temperature may drop as low as 5°C during the flow, what is the heat requirement?

At 5°C the heat of vaporization is 192,000 kJ/m³. At a flow rate of 5m³/hour the heat required is 5 x 192,000 = 960,000 kJ/hr or a minimum line heater size of 0.91 MMBtu/hr. Given efficiencies and requirements a minimum 1 MMBtu/hr line heater is required.
6.0 **General Information**

General Liquefied Petroleum Gas (LPG) Properties:

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical Pressure</td>
<td>4247.66 kPa</td>
</tr>
<tr>
<td>Critical Temperature</td>
<td>96.675 °C</td>
</tr>
<tr>
<td>Boiling Point at Atm. Pressure</td>
<td>-44 °C</td>
</tr>
<tr>
<td>Freezing Point</td>
<td>-188 °C</td>
</tr>
<tr>
<td>Specific Gravity of Liquid</td>
<td>0.51 (water = 1.00)</td>
</tr>
<tr>
<td>Specific Gravity of Vapor</td>
<td>1.53 (air = 1.00)</td>
</tr>
<tr>
<td>1 m³ liquid</td>
<td>510 kg</td>
</tr>
<tr>
<td>1 m³ liquid</td>
<td>272 m³ vapor</td>
</tr>
<tr>
<td>1 kg</td>
<td>0.534 m³ vapor</td>
</tr>
</tbody>
</table>

Above factors are based upon atmospheric pressure, 101.3 kPa, and at ambient temperature, 15°C, as applicable. Physical properties of LPG will vary little within the allowed HD5 composition.

LPG Composition:

Vantage Frac typically utilizes LPG provided to a specification denoted as ‘HD5’. A summary of the HD5 LPG composition specification is as follows (vol %):

<table>
<thead>
<tr>
<th>Component</th>
<th>Volume %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propane (C3H8)</td>
<td>90% minimum</td>
</tr>
<tr>
<td>Propylene</td>
<td>5% maximum</td>
</tr>
<tr>
<td>Butane (C4H10)</td>
<td>2% maximum</td>
</tr>
<tr>
<td>Iso-Butane</td>
<td>1.5% maximum</td>
</tr>
<tr>
<td>Methane (CH4)</td>
<td>1.5% maximum</td>
</tr>
</tbody>
</table>

Useful Conversions:

1 kJ/hour = 0.94782 Btu/hour
1 kJ/hour = 2.77778 x 10⁻⁴ kilowatt
1 Btu/hour = 0.0002931 kilowatt
1 kJ/m³ = 2.683 x 10⁻² Btu/ft³
1 m³ liquid propane = 272 m³ vapor (101.3 kPa, and 15°C)
7.0 LPG Hazards

- LPG is approximately twice as heavy as air when in gas form, will tend to sink to the lowest possible level and will accumulate in low areas.
- LPG in liquid form can cause severe cold burns to the skin owing to its rapid vaporization.
- Vaporization can cool equipment so that it may be cold enough to cause cold burns.
- LPG forms a flammable mixture with air in concentrations of between 2% and 10%.
- LPG can be a fire and explosion hazard if stored or used incorrectly.
- Vapor/air mixtures arising from leakages may be ignited some distance from the point of escape and the flame can travel back to the source of the leak.
- At very high concentrations vapor can have an anesthetic effect and subsequently become an asphyxiant by diluting the available oxygen.
- A component that has contained LPG is normally empty but may still contain LPG vapor and be potentially dangerous.
- Refer to the Material Safety Data Sheet for LPG (Liquefied Petroleum Gas) for complete safety information.

Note:
Though liquid under moderate pressures, LPG returns are flammable gases and must be either flared, gathered into pressurized tanks or directed to a pipeline for recovery at facilities. At no time should LPG returns be directed to the atmosphere or non-pressure tanks.

LPG flowback rates beyond capacity of surface test equipment may result in LPG liquid at the flare stack. Monitor separator outlet conditions to avoid this potentially dangerous situation.

8.0 Associated Services Recommendations

8.1 N2 Blanket for Associated Services Following a 100 % LPG Fracture Treatment

The best practice and recommendation after an LPG fracture treatment, when additional associated service, such as wireline, coiled tubing or snubbing unit is anticipated to perform services on a well that contains 100% LPG below the well head, is to place an N2 blanket on top of the LPG below the well head. This can be done with the GASFRAC N2 Unit once the fracturing equipment is purged and rigged out.

The N2 blanket allows the associated service to initially have N2 at all their surface connections prior to running into the well bore. Rule of thumb is to place, approximately, a 250m in length N2 blanket below the wellhead. At 25 MPa, 20°C a 250 m N2 blanket in 114 mm casing would be approximately 500 m³ of N2. This volume will change based on hole capacity, surface pressure and field requirements.

8.2 Clean outs with Coiled Tubing Units

Ideally, coil tubing work that requires the ability to circulate back to surface should be delayed until the well has been flowed to a point that liquid LPG is not present on surface and the wellbore is in a vapor phase. The reason to wait for the vapor phase is that the ability to circulating liquid LPG from the wellbore will be limited to the capacity of the line heater and flow back equipment on surface. With anticipation of sand to be returned to surface it is
recommended that the flow back equipment to be configured similar to Figure 2. Closed System Flow Back Schematic: A configuration for oil and liquid production with contingency for sand production.

The ability to lift proppant in ungelled LPG is also limited due to its very low viscosity (< 1 cp) and low drag properties of LPG.

In a proppant cleanout situation where proppant is anticipated to be above the perforations and may cause a sand bridge plug, the well should be flowed until either the proppant is recovered or a sand bridge is created and the surface pressure falls below 100 Psi. With a pressure below 100 Psi, and with continued flowing, the hydrostatic head of the liquid LPG will begin to vaporize off until it reaches the sand bridge plug. This usually happens overnight, or while waiting for a coiled tubing unit to respond to the well. This process of vaporizing the LPG above the sand bridge plug allows for a sand cleanout to be initiated in a vapor phase; reducing the demands of the surface line heater and flow back equipment; and results in an efficient environment to meet the requirements of the cleanout operation.

8.3 Circulating Mediums for Well Servicing after a Liquid LPG Fracture Treatment

Circulating mediums for sand cleanouts will vary based on the wellbore configuration and well conditions, and should be discussed in detail with the coiled tubing unit’s technical support.

Rules of the Thumb considerations for a circulating medium after a 100 % LPG fracture treatment.

Fluid can be used that is compatible with the formation and LPG. Water or methanol water blends should be avoided both on a technical and operational perspective. Technically, water can imbibe in the near wellbore causing a potential water block. Operationally, water may freeze if it is allowed to mix with liquid LPG and the LPG vaporizes due to a pressure drop.

Stabilized hydrocarbons, such as refined fracturing oil, is most suitable liquid medium based on compatibility with the formation and LPG. Surface fluid management process needs to be defined as the returned “frac oil” fluids will contain dissolved LPG, and should be stored in a pressurized unit and vented to a flare storage tank. Open tanks on location should be avoided.

Nitrogen can be used based on annular flow rate requirements as recommended by the coil tubing Services Company. Special consideration when using N2 is that after an LPG fracture treatment the proppant is described as “dry” and dry proppant is difficult to lift from a wellbore. To compensate for the “dry” proppant effect, a 2 or 3m³ energized fluid sweep once at TD will maximize the sand clean out efficiency. Once again, surface fluid management process should not allow any returned liquids to be stored in an open tank.

Stabilized hydrocarbon fluids commingled with N2 can also be considered. Please review fluid and nitrogen recommendation with the coil tubing Service Company.
<table>
<thead>
<tr>
<th>Common Flammable Gas or Vapors</th>
<th>Explosive Limits (% by vol. In air) LEL</th>
<th>Explosive Limits (% by vol. In air) UEL</th>
<th>Flash Point °C</th>
<th>Vapour Density Air = 1.0</th>
<th>Ignition Temp. °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonia</td>
<td>15.0</td>
<td>28.0</td>
<td>Gas</td>
<td>0.58</td>
<td>630</td>
</tr>
<tr>
<td>Butane</td>
<td>1.8</td>
<td>9.0</td>
<td>Gas</td>
<td>2</td>
<td>410</td>
</tr>
<tr>
<td>Carbon Monoxide</td>
<td>12.5</td>
<td>74.0</td>
<td>Gas</td>
<td>0.97</td>
<td>570</td>
</tr>
<tr>
<td>Diesel</td>
<td>0.3</td>
<td>10.0</td>
<td>52</td>
<td>&gt; 3.0</td>
<td>&lt; 171</td>
</tr>
<tr>
<td>Ethane</td>
<td>3.0</td>
<td>12.5</td>
<td>Gas</td>
<td>1</td>
<td>472</td>
</tr>
<tr>
<td>Hydrogen Sulphide</td>
<td>4.0</td>
<td>45.0</td>
<td>Gas</td>
<td>1.19</td>
<td>260</td>
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<tr>
<td>Ethyl Alcohol</td>
<td>3.3</td>
<td>19.0</td>
<td>13</td>
<td>1.59</td>
<td>365</td>
</tr>
<tr>
<td>Methanol</td>
<td>6</td>
<td>7.6</td>
<td>16</td>
<td>1.1</td>
<td>464</td>
</tr>
<tr>
<td>Methane</td>
<td>5.0</td>
<td>15.0</td>
<td>Gas</td>
<td>0.55</td>
<td>538</td>
</tr>
<tr>
<td>Propane</td>
<td>2.2</td>
<td>10.0</td>
<td>Gas</td>
<td>1.5</td>
<td>450</td>
</tr>
<tr>
<td>Toluene</td>
<td>1.3</td>
<td>7.0</td>
<td>34</td>
<td>3.14</td>
<td>535</td>
</tr>
<tr>
<td>Common Frac Oils</td>
<td>1.0</td>
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<td>Gas</td>
<td>&lt; 1.0</td>
<td>200</td>
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<tr>
<td>Gasoline</td>
<td>1.3</td>
<td>8.0</td>
<td>-42</td>
<td>3.2</td>
<td>&gt; 277</td>
</tr>
</tbody>
</table>

Well Testing and Fluid Handling, Industry Recommended Practice (IRP), Volume 4 – 2007
9.0 Associated Safety Services Recommendations
9.1 Ignition Source Suppression
ATTACHMENT I - Propane Saturation Chart
Comparison Chart for 75% Propane - 25% Butane

ATTACHMENT II- Butane -Propane Mixtures Saturation Chart
Propane - Heat of Vaporization
Volume Basis

ATTACHMENT III - Propane Heat of Vaporization Chart