Considerations for Sampling Wet, High Pressure, and Supercritical Natural Gas

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Introduction

○ The key to analyzer performance and accurate analysis is proper sample conditioning system (SCS) design and operation.
  - If designed incorrectly, it will result in the largest source of problems for the analyzer and compromise the integrity of the sample.

○ The sample conditioning system consists of all components which contact the sample.
Sample Conditioning System Tasks

- a) Extract a representative sample of the gas phase
- b) Reduce (regulate) the pressure
- c) Transport the sample to the analyzer without changing its composition
- d) Protect the analyzer (analyzer “safety net”)
- e) Control flow rate
- f) Remove contaminants
Sample integrity MUST be maintained during the sample conditioning process.

Preserve sample integrity by:

- Removing contaminants (solids and liquids), when present, in the pipeline.
- Reducing (regulating) the pressure **without traversing the phase envelope**.
- Maintaining the sample in the gas phase at all times after extraction.
  - At least 30°F of de-saturation is required by the API 14.1 standard to keep away from the hydrocarbon dew point (HDP).
In order to design, operate, and troubleshoot sample conditioning systems one must know some basic Chemistry & Physics related to sample conditioning.
Vapor/Liquid Equilibrium

What Happens?

Gas Phase Composition Altered

Pressure Decrease

Gas / Vapor Phase

Liquid Phase

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Vapor/Liquid Equilibrium

What Happens?

- Gas / Vapor Phase
- Liquid Phase

Increase

Pressure

Gas Phase Composition Altered
Key Point:

When liquid is entrained in the source gas, changes in either the pressure or the temperature will change the gas phase composition.
The first step in sampling natural gas is the extraction process.

- The most severe problems are encountered during sample extraction.
What is a “representative” sample?

- Industry standards are not absolutely clear on the definition of “representative” when liquid is present in the source gas.
  - There is also a lack of clear consensus in the industry on this subject.
- There is NO industry standard that covers the sampling of wet or supercritical gases.
- How we define a representative sample is the key to how the sample is conditioned.
How do the industry standards define what a “representative” sample is?

- The standards imply that a representative natural gas sample when liquid is present in the source consist of:
  - “The gas phase at the prevailing pressure and temperature of the source gas at the point of sampling.”
Entrained liquid must be separated

- No technology is available for extracting a gas sample containing a representative amount of entrained liquid
  - Making matters more difficult is the fact that liquid is constantly changing forms in the pipeline.
- This is backed by the API 14.1 standard (Appendix B, Section B.3 - “Multi-phase flow”)
  - It states, in summary, that current sampling technology is not sufficiently advanced to obtain a sample representing both phases.
When liquids are present, we CANNOT:

- Heat tracing (or ambient warmer than gas)
- Gas warmer than ambient
- Can’t heat
- Can’t cool
- Can’t drop pressure internally
- Can’t drop pressure externally
- Can’t ignore the liquid!
Since we cannot ignore the liquid, what can we do?

1. Separate the liquid from the gas phase at line conditions of pressure and temperature.
   - Use a membrane tipped probe inserted vertically into the sample source to accomplish this task.

2. Take steps to “de-saturate” the sample.
   - Drop the pressure
   - Increase the temperature
Caution: Improper Sequence of events

- If steps to de-saturate (pressure reduction and heating) the sample were taken BEFORE liquid was separated at line conditions, the following are likely to occur:
  - Liquids (an arbitrary amount) would become vaporized
  - Vapor composition is altered (ie-richer)
    - BTU value is increased
  - Physical constants calculated from the composition are incorrect
    - Flow (volume) calculations are incorrect
  - Monetary value assigned to Natural Gas is incorrect
Phase Separation Membrane

Gas Flows Through Freely

Liquid is Separated

Chemically inert, NOT chemically selective

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Section 7.3.3

- “An acceptable method for removal of unwanted contaminants is a membrane filter inserted directly in the line.”

Appendix B.1.8

- To effectively separate unwanted liquids, the device must be operating at flowing temperature and pressure conditions.
Membrane Tipped Probe

Membrane Tipped Probe

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THE USE OF PHASE DIAGRAMS IN THE DESIGN & OPERATION OF A NATURAL GAS SYSTEM
1. Liquid Region

3. Phase Envelope
   “Multi-Phase Region”

2. Vapor Region

4. Supercritical Fluid Region

Critical Point

Cricondenbar

Cricondentherm

Dew Point Curve

Bubble Point Curve

Pressure - PSIA

Temperature - °F

Diagram Constant
- Pressure: 14.70 PSIA
DEFINING THE “PRACTICAL” TEMPERATURE
Insertion Pressure Regulators are not 100% effective in preventing J-T cooling.

- Note that insertion pressure regulators are designed to “offset” or prevent excessive Joule-Thomson (J-T) cooling during pressure reduction.
  - This is accomplished by having the pressure reduction valve located in a section of the sample probe which is inside of the pipeline. This allows the sample gas to be “heat sunked” to the process gas.
Insertion Pressure Regulators are not 100% effective in preventing J-T cooling (continued)

- Experience has shown the actual “practical” temperature achieved during pressure reduction with an insertion regulator to be near the midpoint of the adiabatic (no heat transfer) and isothermal (without temperature change) temperature points.
  - The “practical” temperature point will be used in this discussion for guidance in the design and operation of sample systems.
Defining the practical temperature

Critical Point

(80°F, 1700 PSI)

Adiabatic

Practical

Isothermal

Phase Envelope

Insertion Regulator Adiabatic

Insertion Regulator - Isothermal

Insertion Regulator - Practical Temp.
PROBLEMS ENCOUNTERED WHEN SAMPLING & CONDITIONING WET, HIGH-PRESSURE, AND SUPERCRITICAL NATURAL GAS & SOLUTIONS
Problem # 1

How does one extract & condition a “representative” sample when liquid in any form is present in the gas sample (i.e.- “wet” gas)?
Source gas contains entrained liquid ("wet" gas)
In order to arrive at a solution, one must determine the following:

- Determine what type of probe should be used
- Determine if internal or external pressure regulation is required
- Determine if heating is required
  - In order to make these determinations, a phase diagram for the gas composition to be extracted should be utilized.
Solution for “wet” gas

1) Separate liquid inside of the pipeline

- A “phase separation” membrane tipped probe may be used for this purpose.
- Removing liquid externally is not practical because line conditions would have to be maintained EXACTLY as they are in the pipeline.
Source gas contains entrained liquid ("wet" gas)
Gas Phase Composition of “Wet” Gas
Will an insertion regulator work?

Critical Point
(75F, 1400 PSI)
2) Plot a new phase diagram using ONLY the GAS PHASE composition to determine if an insertion regulator can be used or if a heated regulator is required.
Gas Phase Composition of “Wet” Gas
Will an insertion regulator work?

Critical Point
A (75F, 1400 PSI)
Gas Phase Composition of “Wet” Gas

Will a heated, single-stage regulator work?

Critical Point

(130°F, 1400 PSI)
Source gas contains entrained liquid ("wet" gas)
If source conditions were at Point B instead of Point A, would an insertion regulator work?
Gas Phase Composition of “Wet Gas”
Will an insertion regulator work?

(82F, 600 PSI)
Problem # 2

How does one extract & condition a “representative” sample from a supercritical or high pressure natural gas source, even though it does not contain entrained liquid?
1. Liquid Region

2. Vapor Region

3. Phase Envelope
   “Multi-Phase Region”

4. Supercritical Fluid Region

Critical Point

Cricondonbar

Cricondentherm

Bubble Point Curve

Dew Point Curve

Retrograde

Pressure

Temperature

14.70 PSIA
In order to arrive at a solution, one must determine the following:

- Determine what type of probe should be used
- Determine if internal or external pressure regulation is required
- Determine if heating is required
  - In order to make these determinations, a phase diagram for the gas composition to be extracted should be utilized.
Source pressure and temperature conditions (Point A) of this composition are in a supercritical condition. A pressure reduction without heating will cause the sample to traverse the phase envelope.
Solution for extracting & conditioning the supercritical natural gas sample on previous slide

- Extract the sample under conditions which ensure the pressure and temperature changes do not allow the sample to change from its supercritical state.

- Transfer the sample to an external heated multi-stage regulator through a sample line heated at least 30°F above the cricondentherm temperature.
  - Multiple stages of pressure regulation, with re-heating of the sample gas between stages is recommended.
Multiple stages of pressure regulation, with reheating of the sample gas between stages is recommended.
Sampling High Pressure Gas

Although the focus of the last example was on sampling a supercritical gas (also high pressure), the considerations are the same for a high pressure gas. The following will need to be determined:

- Determine what type of probe should be used
- Determine if internal or external pressure regulation is required
- Determine if heating is required
  - In order to make these determinations, a phase diagram for the gas composition to be extracted should be utilized.
Summary

- The recommendations in this presentation are based on experience in similar circumstances.
- The sample extraction process for high pressure, wet, or supercritical gases is the most critical step in the analytical process.
  - Sample will be invalid if this step is performed incorrectly
- Another key step is pressure regulation
Summary

- Design or operation of a sample system for wet, high pressure or supercritical natural gas requires a basic knowledge of thermodynamics.
- Understanding phase diagrams is a “must” for making sample conditioning decisions.
- The API 14.1 standard is a good reference even though its scope is limited to gases at or above their hydrocarbon dew point.