

# FUNDAMENTALS OF SAMPLING NATURAL GAS FOR BTU DETERMINATION

Class # 5310

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## **ABSTRACT**

This paper discusses the fundamentals of extracting, conditioning, and transporting natural gas samples for “on line” BTU analysis.

## **INTRODUCTION**

It has long been recognized that the largest source of error in the analysis of natural gas is the sample conditioning system (SCS). The sample conditioning systems consist of all components through which the sample gas travels from its source, typically a pipeline, to the gas chromatograph (GC) inject valve. The purpose of the sample conditioning system is to extract a natural gas sample that is representative of the source, transport it to an “on line” gas chromatograph, and in the process condition it so that it is compatible with the analyzer.

Conditioning consist mainly of excluding unwanted liquids and solids, regulating the pressure and flow, and heating to maintain the sample gas well above its hydrocarbon dew point temperature<sup>(1)</sup>. During the entire sample conditioning process the sample gas must not undergo any changes in its composition.

Understanding the fundamentals of proper sample conditioning is an absolute necessity for individuals who must design, maintain, or purchase analyzer systems for BTU determination of natural gas. This presentation will cover the sample conditioning system basic tasks, pertinent industry standards, underlying science involved, and the basic design of natural gas sample conditioning systems.

## **EXTRACTING THE NATURAL GAS SAMPLE**

The first task for the sample conditioning system is to extract a representative natural gas sample. A sample probe is utilized for that purpose. In order to select, install and maintain the sample probe one must first know what constitutes a “representative sample”.

### **WHAT IS A REPRESENTATIVE SAMPLE OF NATURAL GAS?**

The definition of “representative sample” has been the subject of much debate in recent years. Since this definition also defines the sample extraction objective it is imperative that it is well understood. The central area of disagreement has centered around whether or not liquid in the source should be included in the sample gas. In short, there is no current technology available in the world suitable for extracting a sample of natural gas having the same proportion of liquid as exist in the source gas. There are elaborate isokinetic sampling techniques which can extract liquid droplets suspended (entrained) in the gas phase. However these techniques are not accurate and are not practical for widespread field use. Additionally, liquid can also be present in the source gas as a film on the inner pipe wall and/or flowing along the bottom of the pipeline. The distribution of liquid which is present as a droplet, film, or flowing stream is generally not known. Therefore sampling only the “entrained” droplets would not be representative of the total liquid present in the source gas.

### **INDUSTRY STANDARDS STAND ON DEFINITION OF A REPRESENTATIVE SAMPLE**

The API 14.1 standard<sup>(2)</sup> by virtue of its scope specifically excludes multi-phase flow<sup>(3)</sup> (free liquid and gas) or supercritical fluids<sup>(4)</sup>. The standard also states that it applies only to natural gas samples which are at or above their hydrocarbon dew point. However, in the standards appendix B.1 the recommended procedure is to eliminate the liquid from the sample.

Not stated is the conditions upon which the liquid is to be eliminated. For those well versed in hydrocarbon vapor/liquid equilibrium characteristics it is obvious that unless the liquid is excluded at the pipeline pressure and temperature condition the composition will be distorted. This can be substantiated by reviewing the GPA 2166 standard<sup>(5)</sup>.

The GPA standard, General note 3 at section 2.1.3, states that “any component of the sampling system that separates unwanted liquids from the sample stream must be operated at flowing line temperature and pressure”.

Reference is made at section 4.2 and 4.3 to the need for removal of free-flowing or entrained liquids and that these liquids are not desired in the vapor phase portion of the accounting system. In the GPA standard 2166 appendix B.1.8 it clearly recommends removal of liquids from the vapor sample at the flowing gas temperature and pressure. In section B.2.1 of the appendix it states that the insertion membrane filter probe meets the requirements for proper liquid removal. Section 7.3.3 also states that a membrane filter inserted directly in the line is suitable for removal of unwanted liquids.

#### ANSWER TO “WHAT IS A REPRESENTATIVE SAMPLE OF NATURAL GAS”?

**A representative natural gas sample is one that represents the vapor phase composition of the natural gas source flowing in a pipeline. Further, if the gas source contains liquid in droplet, film, or flowing stream form it must be removed at pipeline conditions of pressure and temperature. If this process is carried out external to the pipeline care must be taken maintain the pressure and temperature of the source gas from its extraction point and throughout the liquid separation process. Heating the sample or reducing the pressure before liquid is removed will distort the gas phase composition and render the sample unrepresentative.**

These conclusions can be substantiated by reference to the API 14.1 and GPA 2166 standards. Reading these standards is highly recommended for beginning **and** experienced technicians.

#### SAMPLE PROBES

A probe, inserted into the pipeline is recommended in all cases for extracting a representative sample of natural gas.

There are several basic types of sample probes which are in current use. Each type is designed to perform specific functions under certain conditions. They are as follows:

Open end tube – A tube inserted into a pipeline through an appropriate fitting. Its collection end can be cut square or angled. (Figure 1)

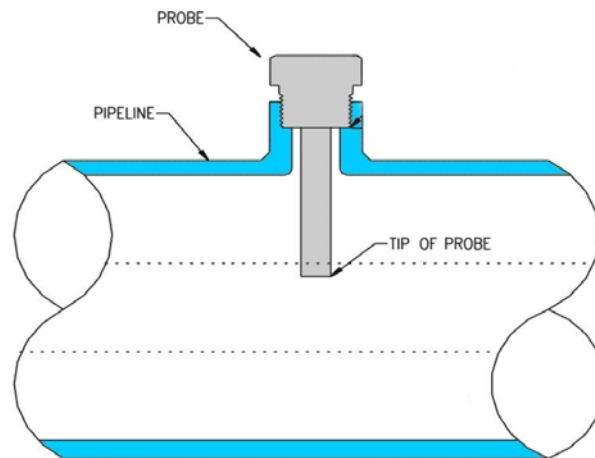


Figure 1 (Probe inserted into a pipeline)

Square cut is recommended. Its purpose is to sample the natural gas away from the pipe wall to avoid liquid contamination.

Membrane tipped probe – A probe designed for insertion into a pipeline for the purpose of extracting a “liquid free” sample of natural gas. A phase separation membrane at its collection end eliminates entrained hydrocarbon liquids from the sample gas. (Figure 2)



Figure 2 (Membrane tipped probe)

The liquid elimination is done inside of the pipeline therefore the gas and liquid are at pipeline conditions of pressure and temperature. This assures compliance with the API 14.1 and GPA 2166 standards for removal of liquids from a natural gas sample.

Pitot probes – A probe designed to sample natural gas, circulate it to a destination, then return the unused gas sample to the pipeline. Not typically utilized for “on line” BTU analysis. (Figure 3)

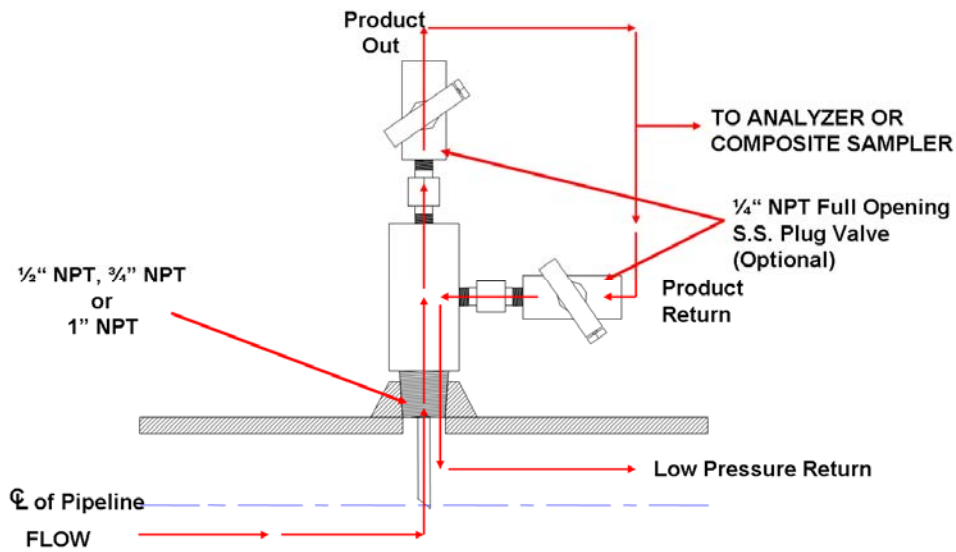


Figure 3 (Pitot tube)

Pressure regulating probes – The pressure regulating probes are designed to reduce and control the sample pressure to a desired level inside of the pipeline. (Figure 4)

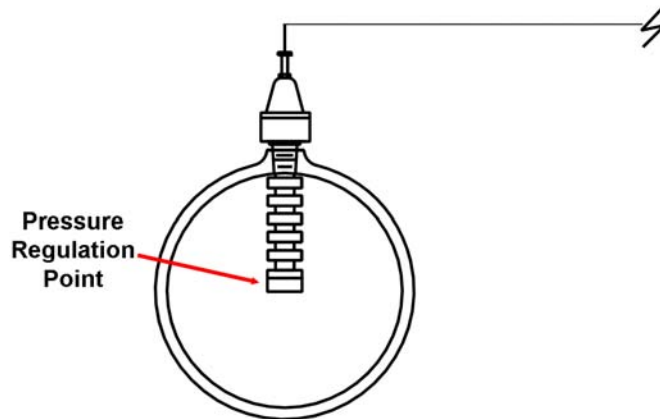


Figure 4 (Pressure regulator probe)

This allows the source gas flowing across the pressure reducing section of the probe to prevent excessive Joules-Thompson (J.T.) cooling of the sample gas as the pressure is lowered. Excessive cooling of the sample could cause condensation of some hydrocarbon components in the sample gas thereby altering its composition. This type of regulator should not be utilized if liquid is likely to be present. The reason is if the sample gas pressure is changed (lowered) with liquid present then the vapor phase composition will not represent the source gas.

Pressure regulating probe with membrane tip – This type of probe is equipped with a phase separation membrane tip which eliminates entrained liquid from the sample gas before it enters the probe's pressure reducing valves. Liquid rejected in this manner drains into the source gas. This prevents sample distortion which would otherwise occur if liquid was present during pressure reduction. The membrane allows the sampling of the true gas phase composition as required by the standards. After sample gas flows through the membrane the pressure is reduced and controlled to a desired level comparable to the "Pressure regulating probe" without a membrane tip. (Figure 5)

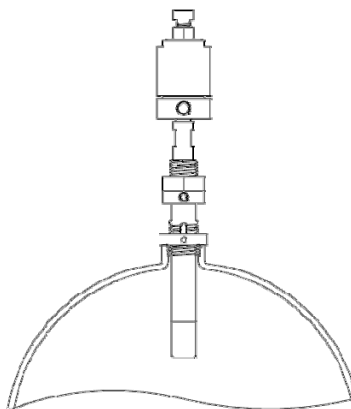


Figure 5 (Pressure regulating probe with membrane)

Insertable under pressure probes – There are three basic classes of probes which are insertable under pressure. The preceding probes (Figure 1 to 5) requires the pipeline to be depressurized during

probe insertion. This limits their use to meter runs or small pipeline sections which are easily depressurized.

A second class of probe can be installed under full line pressure.

One such probe can be installed underline pressure with a removable tool. (Figure 6)



Figure 6 (Probe insertable under pressure with removable tool)

The probe shown in Figure 7 can be installed under line pressure and lowered to variable depths without the use of external insertion tools.

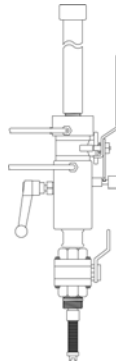


Figure 7 (Probe insertable to varying depths without external tools)

The probes shown in Figures 5 and 6 are installed utilizing a pressure balance technique which does not require a dynamic seal at the pipeline wall.

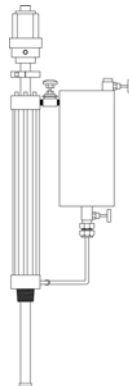


Figure 8 (Insertion probe utilizing pneumatic or hydraulic cylinders to insert the probe)

The probe of Figure 8 utilizes pneumatic or hydraulic cylinders operated by line pressure to insert a probe through a dynamic pressure seal into the pipeline.

A third class requires line depressurization for initial installation of a probe housing.

Thereafter the sample probe can be inserted and retracted without line depressurization. (Figure 9)

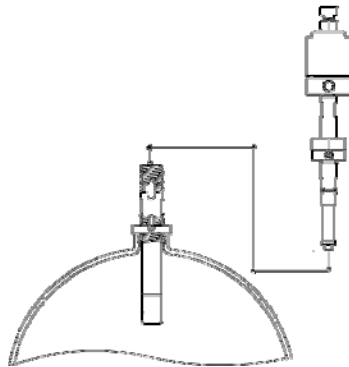


Figure 9 (Housing and Probe)

### PROBE PLACEMENT

The API 14.1 and GPA 2166 standards state that placement of the collection end of the sample probe in the center one-third of the pipe cross-section is an industry practice. Caution is given to possible probe breakage resulting from resonant vibration triggered by vortex shedding at high gas velocities. A table and calculation provide a means for determining the maximum probe insertion depth for a given probe design. For more information on this subject refer to section 7.5.2 in the GPA 2166 standard or section 7.4.1 in the API 14.1 standard. Both standards recommend using probes less than ten inches in length. The length referenced is not the distance between the inner pipe wall and probe tip but rather the length between the point of attachment and the probe tip. (Figure 10)

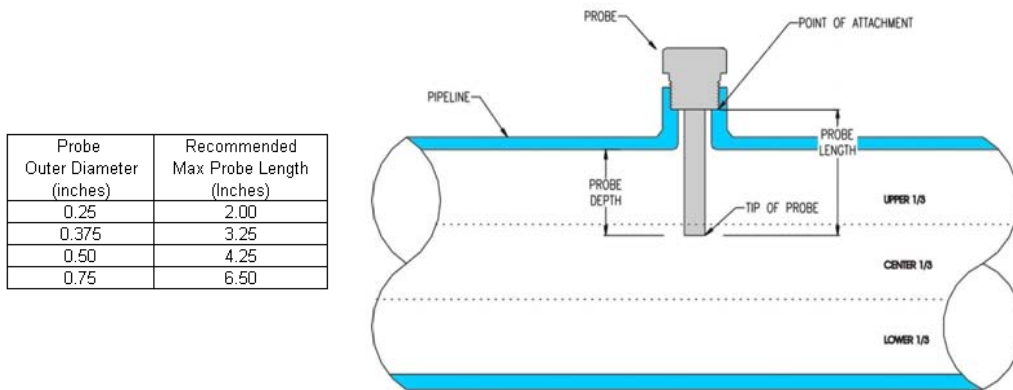


Figure 10 (Probe dimensions used to determine recommended probe length-taken from API 14.1 and GPA 2166 Standards)

The point of attachment in some cases can be several inches from the pipe wall. It should be noted that as probe length increases its natural resonate frequency is lowered thereby lowering the gas velocity required to trigger potentially destructive vibration.

**The conclusion is that one must consider the maximum source gas velocity anticipated and probe design characteristics before selecting the insertion depth of a sample probe for a specific sample location.**

The probe location recommended by the API 14.1 and GPA 2166 standards is vertical mounting at the top of a horizontal pipe run. It is also recommended that the probe be placed at least five diameters downstream of a disturbing element. The referenced diameters are of the disturbing element, not pipe diameters when the

disturbing element is a tube like protrusion such as a thermocouple well. However, if the disturbing element is an orifice plate, pipe tee or elbow, filter, strainer, etc then the disturbing element diameter is considered to be the inside source gas pipe diameter.

The probe should not be located in any “dead-end” section of pipe where gas is not continually flowing.

### TRANSPORTING AND CONDITIONING THE EXTRACTED NATURAL GAS SAMPLE

Once a vapor sample of natural gas has been extracted from the pipeline it needs to be transported to the gas chromatograph. This is accomplished by flowing the gas through a length of tubing extending from the sample probe location to the gas chromatograph. The recommended material of construction for the tubing is 316 stainless steel. During transportation condensation of gas components must not occur, otherwise the gas composition will no longer be representative of the original gas source. It is important to maintain the sample gas above its hydrocarbon dew point temperature (HCDP) at all times to prevent condensation from occurring. The industry standards recommend maintaining the sample gas at least 30°F above its hydrocarbon dew point temperature due to the uncertainty in determining the dew point. When ambient temperature is likely to dip within 30°F of the hydrocarbon dew point temperature then heat tracing the sample is required. The hydrocarbon dew point temperature can be lowered by reducing the sample pressure thus reducing the heat tracing requirements. The relationship between the gas sample’s pressure, temperature, and hydrocarbon dew point temperature can be calculated by utilizing an “Equation of State” (EOS) software program. Utilization of this type of software removes the guess work in designing and operating a sample conditioning system for natural gas. Studying a “phase diagram” (Figure 11) generated by an ‘Equation of State” software package can be a valuable aid in the decision making process when designing a sample conditioning system.

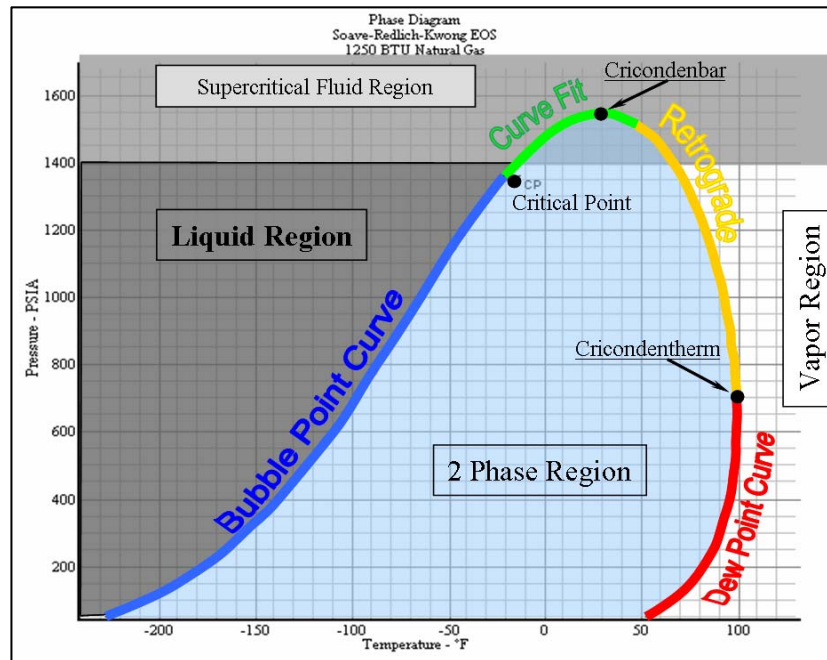


Figure 11 (Phase diagram generated by an “Equation of State” software package)

### LAG TIME

Lag time is defined in the API standard as the time required for a molecule to migrate from the sample probe inlet to the inlet of the analyzer. A more proper definition is the time required for the vapor composition to equilibrate at the analyzer after a step change in the vapor composition entering the sample probe. In some circumstances the higher molecular weight molecules, (such as C6+) due to their adsorption/desorption characteristics, take longer to attain equilibrium than the lower molecular weight molecules (such as methane).

The recommended sample flow rate through the gas chromatograph sample loop/inject valve is usually less than 100 cc’s per minute. This is typically not enough flow to provide a fresh, representative sample at the gas

chromatograph after each analysis cycle. The analysis cycles for gas chromatographs vary but are typically on the order of four minutes.

To reduce the “lag time” to a desired level some of the sample gas arriving at the gas chromatograph is “by passed” and vented. This increases the sample flow rate through the sample transport line thereby decreasing the lag time. Filters and membrane separators usually provide a port for installation of the “by pass” stream line. The “by pass” stream also facilitates the removal of liquids from the filter or separator. A general recommendation for the total sample flow rate in the sample line (analyzer plus Bypass flow) is at least three sample system volumes per minute.

### **ANALYZER PROTECTION**

It is important to filter the sample flowing into the gas chromatograph sample loop/inject valve in order to remove solid and liquid contaminants. This filtration should be performed “at” the gas chromatograph as close as possible to the sample inject valve. The reason being that although upstream filtration may have removed particles and liquids they may be present in the sample gas “at” the analyzer. For example when pipe and tubing fittings are “made up” small bits of metal can be released in the flowing sample gas stream. These metal particles can damage gas chromatograph and sample system valves. Liquid can be present due to condensation of heavy hydrocarbons in the event of upstream filter failure or loss of heat tracing.

Coalescing filters and phase separation membrane based separators may be utilized for filtration at the inject valve location.

**It should be noted that if liquid hydrocarbons are present in the sample gas anywhere down stream of the sample probe the sample is invalid and analysis results should be discarded. Filtration for removal of liquids anywhere external to the pipeline should be for analyzer protection only.**

### **BASIC SAMPLE CONDITIONING DESIGN AND OPERATION**

The basic steps in the sample conditioning are as follows:

Extraction – a probe is recommended. The maximum permissible insertion depth must be calculated based on the specific probe design and source gas velocity. A membrane tipped probe should be utilized if liquid hydrocarbons are likely to be present at any time. Follow guidelines for probe location found in the API 14.1 standard.

Pressure reduction – an insertion type of pressure regulator is recommended to prevent condensation caused by Joule-Thomson cooling. Set the regulator secondary pressure to the lowest pressure that will supply sample to the gas chromatograph at the manufacturers recommended input pressure. A setting between 15 to 20 PSI is typical. Low pressures in the sample line reduce the hydrocarbon dew point temperature which is highly desirable. Reducing the pressure also reduces adsorption of “heavies” on sample conditioning system surfaces and reduces the by pass flow requirement for a desired sample lag time.

Transportation – a 1/8” diameter 316 stainless tubing (seamless type) is recommended for most applications. Minimize the distance between the sample take off point and the analyzer. Calculate or measure the hydrocarbon dew point temperature (HCDPT). If the ambient temperature at anytime can drop to within 30°F of the sample gas HCDPT then heat tracing is required. The entire sample conditioning system, from the probe/pipeline wall intersection to the gas chromatograph inject valve, must be maintained above the hydrocarbon dew point temperature. Otherwise condensation will occur which will distort the sample composition and may damage the analyzer if adequate protection is not provided.

Filtration – Provide coalescing and/or filtration at the analyzer as previously described.

Lag time – adjust the sample by-pass flow rate as previously described to produce the desired lag time.

### **CONCLUSION**

This presentation was intended to provide a basic understanding of the function, design and general operation of the sample conditioning system (SCS) suitable for on line BTU determination by gas chromatography.

It is highly recommended that all personnel involved in the selection, design, operation and maintenance of the aforementioned sample conditioning system receive advanced training on the following subjects:

- a) Use of Equations of State software



- b) Using phase diagrams
- c) A through understanding of the API 14.1 and GPA 2166 standards

## **REFERENCES**

- Mayeaux, Donald P. "Utilizing Equation of State (EOS) Software in Sample Conditioning of Natural Gas Applications", ISHM, 2007
- API, Manual of Petroleum Measurement Standards Chapter 14-Natural Gas Fluids Measurement, Section 1-Collecting and Handling of Natural Gas Samples for Custody Transfer, Sixth Edition, February 2006
- GPA, Obtaining Natural Gas Samples for Analysis by Gas Chromatography
- Liptak, Bela G. Instrument Engineers Handbook, 4<sup>th</sup> ed.
- Liptak, Bela G. Technology and Engineering, 2003

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- (1) hydrocarbon dew point: A temperature at a given pressure at which hydrocarbon vapor condensation begins.
  - (2) API, Manual of Petroleum Measurement Standards Chapter 14-Natural Gas Fluids Measurement, Section 1-Collecting and Handling of Natural Gas Samples for Custody Transfer; Sixth Edition, February 2006
  - (3) multi phase flow: Defined as two or more phases in the stream.
  - (4) Purpose and Scope:
    - The purpose of this standard is to provide a comprehensive guideline for properly collecting, conditioning, and handling representative samples of natural gas that are at or above their hydrocarbon dew point.
    - The standard considers spot, composite, continuous, and mobile sampling systems. This standard does not include sampling of liquid streams.
    - This standard includes comments identifying special areas of concern or importance for each sampling method included. It is intended for custody transfer measurement systems and may be applicable to allocation measurement systems.
    - The accuracy of moisture determinations from samples collected using the recommendations in this standard has not been determined.
    - This standard does not included sampling multi-phase flow (free liquid and gas) or supercritical fluids.

- (5) GPA, Obtaining Natural Gas Samples for Analysis by Gas Chromatography