Standard Guide for
Prediction of Analyzer Sample System Lag Times[1]

INTRODUCTION

Lag time, as used in this guide, is the time required to transport a representative sample from the process tap to the analyzer. Sample system designs have infinite configurations so this guide gives the user guidance, based on basic design considerations, when calculating the lag time of online sample delivery systems. Lag time of the analyzer sample system is a required system characteristic when performing system validation in Practice D3764 or D6122 and in general the proper operation of any online analytical system. The guide lists the components of the system that need to be considered when determining lag time plus a means to judge the type of flow and need for multiple flushes before analysis on any sample.

1. Scope*

1.1 This guide covers the application of routine calculations to estimate sample system lag time, in seconds, for gas, liquid, and mixed phase systems.

1.2 This guide considers the sources of lag time from the process sample tap, tap conditioning, sample transport, pre-analysis conditioning and analysis.

1.3 Lag times are estimated based on a prediction of flow characteristics, turbulent, non turbulent, or laminar, and the corresponding purge requirements.

1.4 Mixed phase systems prevent reliable representative sampling so system lag times should not be used to predict sample representation of the stream.

1.5 The values stated in inch-pound units are to be regarded as standard. No other units of measurement are included in this standard.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D3764 Practice for Validation of the Performance of Process Stream Analyzer Systems

D6122 Practice for Validation of the Performance of Multivariate Online, At-Line, and Laboratory Infrared Spectrophotometer Based Analyzer Systems

3. Terminology

3.1 *Definitions:*

3.1.1 *continuous analyzer unit cycle time*—the time interval required to replace the volume of the analyzer measurement cell.

3.1.2 *intermittent analyzer unit cycle time*—the time interval between successive updates of the analyzer output.

3.1.3 *purge volume*—the combined volume of the full analyzer sampling and conditioning systems.

3.1.4 *sample system lag time*—the time required to transport a representative sample from the process tap to the analyzer.

3.1.5 *system response time*—the sum of the analyzer unit response time and the analyzer sample system lag time.

3.2 *Abbreviations:*

3.2.1 *I.D.*—Internal Diameter

*A Summary of Changes section appears at the end of this standard.

3.2.2 *Re*—Reynolds Number

4. Summary

4.1 The lag time of an analyzer sample system is estimated by first determining the flow characteristics. The flow is assigned as turbulent or non-turbulent to assign the number of purges required to change out the sample. Based on the hardware employed in the sample system an estimation of the lag time can be calculated.

5. Significance and Use

5.1 The analyzer sample system lag time estimated by this guide can be used in conjunction with the analyzer output to aid in optimizing control of blender facilities or process units.

5.2 The lag time can be used in the tuning of control programs to set the proper optimization frequency.

5.3 The application of this guide is not for the design of a sample system but to help understand the design and to estimate the performance of existing sample systems. Additional detailed information can be found in the references provided in the section entitled Additional Reading Material.

6. Basic Design Considerations

6.1 *Acceptable Lag Time*—A one to two minute sample system lag time should be maintained to give acceptable performance. Flow is a key component in the determination of sample system lag time, and in most systems the desired system lag time is impossible to achieve solely with maximum allowable sample flow rate to the analyzer. A fast loop or bypass can be ways to improve lag time by increasing sample velocity. A slipstream is taken from the bypass to feed the analyzer at its optimum flowrate. Excess sample in the slipstream is vented to atmosphere, to flare or to the process stream dependent upon application and regulatory requirements.

6.2 *Physical State of Sample:*

6.2.1 *Liquid Samples*—Pressure drop properties often govern the design of a liquid system. This is due for the most part on the close relationship between pressure drop and system flowrate and the fixed pressure differential available from the process for sample transport. The sizing of the sample components is a tradeoff between pressure drop and sample flowrate. High sample flowrates in small sized component systems cause high-pressure drops and low sample transport times. The same flowrate in a larger tubing system will yield significant improvements in pressure drop through the system, but will also significantly increase the time for sample transport.

6.2.1.1 Users need to perform hydraulic calculations (which are currently outside the scope of this standard) in parallel with the lag time calculcations to ensure that the "design" flow rates from a lag time perspective can actually be achieved with the operating conditions in the field with some contingency for operational variations.

6.2.2 *Vapor Samples*—Vapor phase sampling is governed less by pressure drop and more by pressure compression properties of gases relative to liquids. In compressible gases the higher the pressure in a given volume, the more sample is present in that volume. For this reason, and different from

liquids, the selection and location of pressure regulating devices in the vapor sample system has a significant impact on the overall system design. The optimal location for a high-pressure regulator in a vapor sample is immediately downstream of the sample tap or high-pressure location thereby limiting the volume of the system under high pressure. Since the density of a compressible fluid is a function of the pressure, compressible fluid flow rate calculations are sometimes done over segmental lengths where average properties adequately represent the fluid conditions of the line segment.

6.2.3 *Liquid to Vapor Samples*—A change of phase due to sample vaporization can also impact the sample lag time. The volume change from the liquid phase to the vapor phase is substantial. Typical flow rates in gaseous sample lines downstream of the vaporizer can represent very small liquid feed rates to the vaporizer. Deadheaded sample line lengths upstream of the vaporizer can, in turn, represent appreciable lag times.

6.2.4 *Phase Separation*—This guide is not intended to deal with dual phase samples as the volume and flow characteristics are outside the scope.

6.3 *Sample Temperature*—Temperature also impacts sample system lag time but to a lesser degree relative to pressure. Increased temperature of a sample lowers the sample density thus lowering the amount of sample flow needed to purge a given volume. Temperature impact is generally so small that it is ignored in rough estimations of sample system lag time.

6.4 *Typical Sources of Lag Time to Consider:*

6.4.1 *Process Sample Tap:*

6.4.1.1 Sample taps can be a significant source of lag time if a sampling probe is not used, need to know the design inside the sample stream. See Fig. X1.1.

6.4.1.2 Sample taps can present a problem for liquid vaporizing systems with high volume and low flow on the liquid side. See Fig. X1.2.

Note 1—This refers to the case where the vaporizing regulator is located at the sample tap and one then has a length of liquid filled line from the probe/process interface to the inlet of the vaporizing regulator. This situation can be mitigated by using a sample probe that takes the pressure drop, and subsequent vaporization, at the probe/process interface so that one extracts a gaseous sample only. The sensible heat of the bulk process stream flowing past the tip of the sample probe provides the energy necessary to vaporize the sample that is extracted.

6.4.2 *At-Tap Conditioning:*

6.4.2.1 *Filters and Strainers at Sample Stream*—Depending on design and size these can add large volumes to a non turbulent sample system.

Note 2—For filters with diameters greater than the sample tubing diameter calculate the internal volume and use the 3 times the volume rule to account for the delay attributable to the filter.

6.4.2.2 *Flow or Pressure Regulators*—Internal volume of the regulator(s) are to be included in the system calculation.

6.4.3 *Vaporizing Regulators*—Internal volume of the regulator are to be included in the system calculation.

6.4.3.1 The volume change from a liquid to a gas is on the order of 300 to 600 volumes of gas per volume of liquid so the

lag time of the liquid filled slipstream tubing length from a fast loop to a vaporizing regulator can represent very large lag times. See Fig. X1.3.

6.4.3.2 A system designed on the basis of a good gas volumetric flow rate can represent a very small liquid flow rate.

6.5 Sample delivery tubing needs to be taken into account in the system calculation. This can sometimes be a significant run length depending on the analyzer location to the process stream.

6.5.1 *Sample Conditioning at Analyzer:*

6.5.1.1 *Filtering*—Depending on their design and size, filters can add large volumes to a non turbulent sample system. See Note 2.

7. Procedure

7.1 *Determination of Flow Characteristics:*

7.1.1 Calculate the Reynolds number, *Re*, of each section of the sample system using the tubing / pipe internal diameter (I.D.), the flow velocity, density of the sample stream, and viscosity of the sample stream.

$$Re = [(I.D.)*(Velocity)*(Density)]/Viscosity \qquad (1)$$

NOTE 3—Various forms of this equation exist for different units.

7.1.2 Use Reynolds number *Re* to determine whether the sample flow is turbulent or non-turbulent in a particular section of the sample system.

7.1.2.1 Assume turbulent flow for sections with a *Re* > 4000.

7.1.2.2 Assume non-turbulent flow for sections with a *Re* < 4000.

7.1.2.3 Traditionally, the break point *Re* from laminar flow has been 2100. The region of *Re* > 2100 to *Re* < 4000 is a transition region in that in some systems laminar flow could exist while in other systems, at the same *Re*, eddy formation and turbulent behavior could be observed.

7.1.3 Record the result, turbulent or non-turbulent, for each section of the sample system.

7.2 *Number of Purge Volumes Required:*

7.2.1 Assume a single purge volume is sufficient for system portions with turbulent flow, *Re* > 4000. See Figs. X1.4 and X1.5.

7.2.2 Assume three purge volumes are required for adequate sample exchange in systems with non-turbulent flow, *Re* < 4000 (laminar or transition). See Fig. X1.6.

NOTE 4—Three purge volumes are probably excessive for some system components but helps compensate for items that are difficult to purge.

7.2.3 Using the results from 7.1.3 record for each section the number of purge volumes required.

7.3 *Calculating Sample System Lag Time:*

7.3.1 Calculate the internal volume of each section of the sample system.

7.3.2 Calculate the lag time of each section with the volume, number of purge volumes and flow through the section.

$$\text{Sample System Lag Time} = (\text{Internal Volume} * \qquad (2)$$

$$\text{Number of Required Purge Volumes/Flow})$$

7.3.3 Sum all the section lag times to determine the lag time for the full analyzer sample system.

NOTE 5—Lag time calculation is different for gases and liquids due to the compressive nature of gaseous samples. Basically the amount of gaseous sample present in a given volume equals the number of atmospheres of pressure applied to the system times the volume of the system (at a fixed temperature). A guide for this is to take the system volume and multiply it by the pressure in Bar to give the volume present in the system. This has to be factored into the calculation to determine the time and flow required to obtain one purge volume.
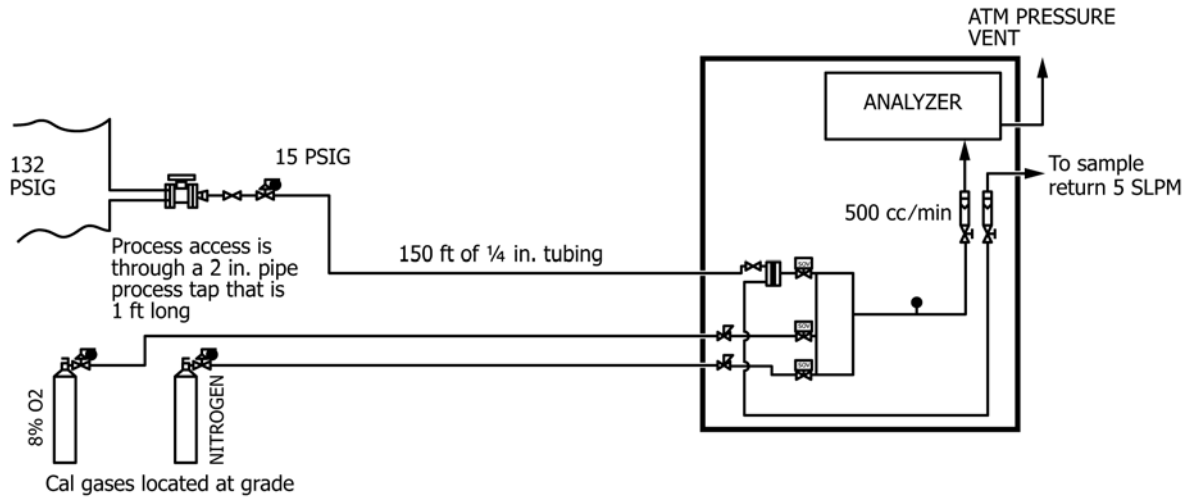
8. Keywords

8.1 analyzer; lag time; on-line; sample systems; sampling; response
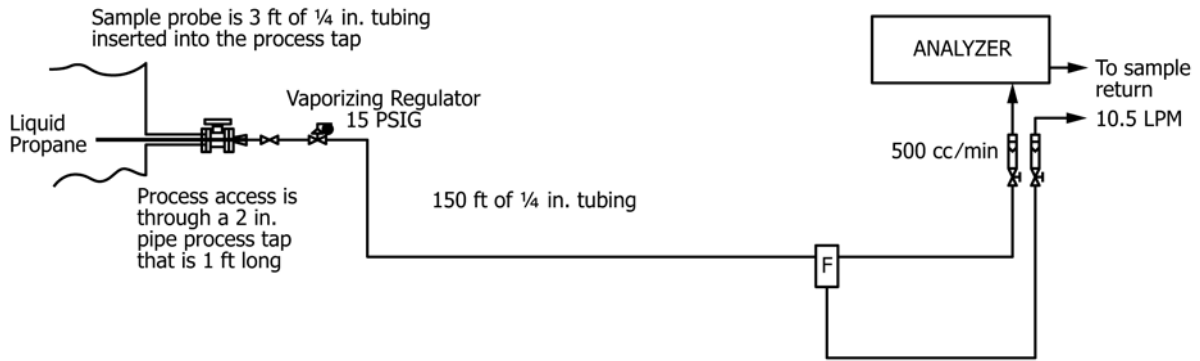
APPENDIX

(Nonmandatory Information)

X1. EXAMPLE LAG TIME CALCULATIONS

See Figs. X1.1-X1.6.

	Process Tap	Tap Sam Cond	Sample Transport	Analyzer Sam Sys	Lagtimes	
Molecular weight of sample gas	30	30	30	30	seconds	
Temperature of sample gas, °C	25	25	25	25		
Approximate gas density (lbs/cf)	0.7637	0.7637	0.1546	0.1546		
Viscosity of sample gas (cP)	0.0171	0.0171	0.0171	0.0171		
Reynolds Number	165	NA	1829	NA		
Pressure (PSIG)	132	132	15	15	89.71	1 Purge 75%R
L (feet)	1	NA	150	NA	179.42	2 Purge >93%R
ID (inches)	2.0000	NA	0.1800	NA	269.12	3 Purge >97%R
Flow (SLPM)	5.5000	5.5000	5.5000	0.5000	358.83	4 Purge >98%R
Volume (litres)	0.6175	0.0100	0.7502	0.0200		
Pressure corrected purge volume	6.1620	0.0998	1.5157	0.0404		
Single Purge Time (seconds)	67.2223	1.0887	16.5354	4.8490		
Average Velocity (FPS)	0.0149	NA	9.0714	NA		
Flow Type (w/o Transition)	Non Turbulent	Non Turbulent	Non Turbulent	Non Turbulent		
Non-Turb Components (Sec)	67.2223	1.1000	16.5354	4.8500	89.71	
Turbulent Components (Sec)	0.0000	0.0000	0.0000	0.0000	0.00	

FIG. X1.1 Gas Sample Without Tap Probe

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Sample probe is 3 ft of ¼ in. tubing
inserted into the process tap

ANALYZER → To sample return

10.5 LPM

Vaporizing Regulator
15 PSIG

Liquid Propane

500 cc/min

Process access is through a 2 in. pipe process tap that is 1 ft long

150 ft of ¼ in. tubing

F

Lag Time Calc

SS Component	Seconds	Flow Characteristic	Seconds x Purges
Liq Process Tap	21.40	Non-Turbulent	64.20
Vaporizing Reg	28.60	Non-Turbulent	85.80
Vapor Transport	8.30	Turbulent	8.30
Sample Cond	4.80	Non-Turbulent	14.40
		Total	172.7000

Liquid Propane	Process Tap	Tap Sam Cond	Vaporized Propane	Sample Transport	Analyzer Sam Sys
Approximate liq density (lbs/cf)	31.6	31.600	Molecular weight of sample gas	44	44
Viscosity of liquid (cP)	0.120	0.120	Temperature of sample gas, °C	25	25
Reynolds Number	822	1	Approximate gas density (lbs/cf)	0.227	0.227
L (feet)	3.0	NA	Viscosity of sample gas (cP)	0.017	0.017
ID (inches)	0.180	NA	Reynolds Number	5365	1
Flow (LPM)	0.042	0.042	Pressure (PSIG)	15.0	15.0
Volume (litres)	0.015	0.020	L (feet)	150.0	NA
Single Purge Time (seconds)	21.435	28.571	ID (inches)	0.180	NA
Average Velocity (FPS)	0.140	NA	Flow (SLPM)	11.00	0.50
Flow Type (w/o Transition)	Non-Turbulent	Non-Turbulent	Volume (litres)	0.750	0.020
Non-Turb Components (Sec)	21.435	28.571	Pressure corrected purge volume	1.516	0.040
Turbulent Components (Sec)	0.000	0.000	Single Purge Time (seconds)	8.268	4.849
			Average Velocity (FPS)	18.143	NA
			Flow Type (w/o Transition)	Turbulent	Non Turbulent
			Non-Turb Components (Sec)	0.000	4.849
			Turbulent Components (Sec)	8.268	0.000

FIG. X1.2 Vaporizing Regulator Near Tap
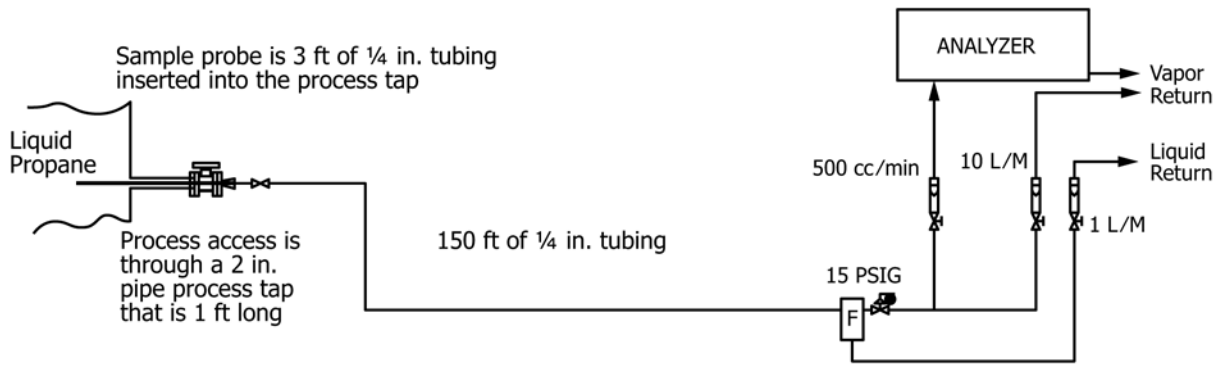
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Lag Time Calc			
SS Component	Seconds	Flow Characteristic	Seconds x Purges
Liq Process Tap	0.90	Turbulent	0.90
Liq Transport	45.00	Turbulent	45.00
Vaporizing Reg	15.00	Non-Turbulent	45.00
Sample Cond	0.10	Non-Turbulent	0.30
		Total	91.2000

Liquid Propane	Process Tap	Sample Transport	Analyzer Sam Sys	Vaporized Propane	Analyzer Sam Sys
Approximate liq density (lbs/cf)	31.600	31.600	31.600	Molecular weight of sample gas	44.000
Viscosity of liquid (cP)	0.120	0.120	0.120	Temperature of sample gas, °C	25.000
Reynolds Number	19570.474	19570.474	1.000	Approximate gas density (lbs/cf)	0.227
L (feet)	3.000	150.000	NA	Viscosity of sample gas (cP)	0.017
ID (inches)	0.180	0.180	NA	Reynolds Number	1.000
Flow (LPM)	1.000	1.000	0.040	Pressure (PSIG)	15.000
Volume (litres)	0.015	0.750	0.010	L (feet)	NA
Single Purge Time (seconds)	0.900	45.013	15.000	ID (inches)	NA
Average Velocity (FPS)	3.332	3.332	NA	Flow (SLPM)	10.500
Flow Type (w/o Transition)	Turbulent	Turbulent	Non-Turbulent	Volume (litres)	0.010
Non-Turb Components (Sec)	0.000	0.000	15.000	Pressure corrected purge volume	0.020
Turbulent Components (Sec)	0.900	45.013	0.000	Single Purge Time (seconds)	0.115
				Average Velocity (FPS)	NA
				Flow Type (w/o Transition)	Non Turbulent
				Non-Turb Components (Sec)	0.115
				Turbulent Components (Sec)	0.000

FIG. X1.3 Vaporizing Regulator Near Analyzer

	Process Tap	Tap Sam Cond	Sample Transport	Analyzer Sam Sys	Lagtimes	
Molecular weight of sample gas	30	30	30	30	seconds	
Temperature of sample gas, °C	25	25	25	25		
Approximate gas density (lbs/cf)	0.7637	0.7637	0.1546	0.1546		
Viscosity of sample gas (cP)	0.0171	0.0171	0.0171	0.0171		
Reynolds Number	5155	NA	5155	NA		
Pressure (PSIG)	132	132	15	15	11.68	1 Purge 75%R
L (feet)	3	NA	150	NA	16.92	2 Purge >93%R
ID (inches)	0.1800	NA	0.1800	NA	22.16	3 Purge >97%R
Flow (SLPM)	15.5000	15.5000	15.5000	0.5000	27.39	4 Purge >98%R
Volume (litres)	0.0150	0.0100	0.7502	0.0200		
Pressure corrected purge volume	0.1497	0.0998	1.5157	0.0404		
Single Purge Time (seconds)	0.5796	0.3863	5.8674	4.8490		
Average Velocity (FPS)	5.1757	NA	25.5649	NA		
Flow Type (w/o Transition)	Turbulent	Non Turbulent	Turbulent	Non Turbulent		
Non-Turb Components (Sec)	0.0000	0.3860	0.0000	4.8500	5.24	
Turbulent Components (Sec)	0.5796	0.0000	5.8674	0.0000	6.45	

FIG. X1.4 Gas Sample—Fast Response
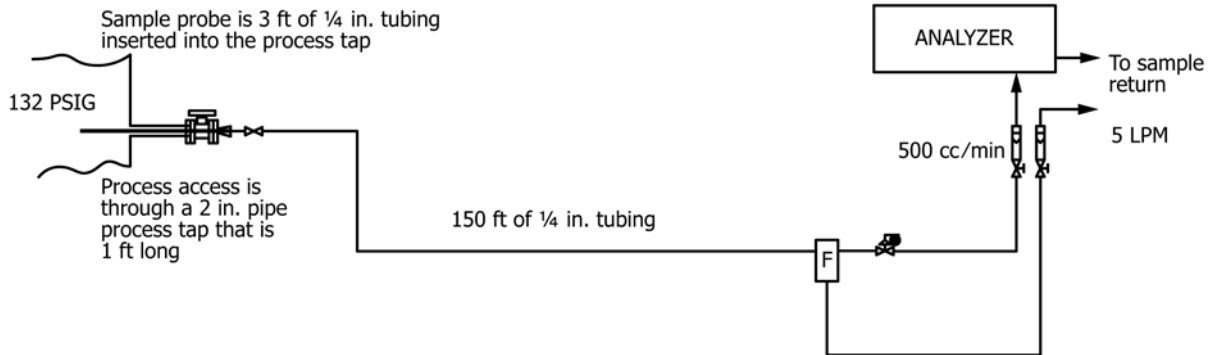
	Process Tap	Tap Sam Cond	Sample Transport	Analyzer Sam Sys	Lagtimes	
Approximate liq density (lbs/cf)	61.0	61.0	61.0	61.0		
Viscosity of liquid (cP)	1.0	1.0	1.0	1.0		
Reynolds Number	24934	NA	24934	NA		
L (feet)	3.0	NA	150.0	NA	14.35	1 Purge 75%R
ID (inches)	0.1800	NA	0.1800	NA	20.35	2 Purge >93%R
Flow (SLPM)	5.5000	5.5000	5.5000	0.5000	26.35	3 Purge >97%R
Volume (litres)	0.0150	0.0000	0.7502	0.0500	32.35	4 Purge >98%R
Single Purge Time (seconds)	0.1637	0.0000	8.1842	6.0000		
Average Velocity (FPS)	18.3280	NA	18.3280	NA		
Flow Type (w/o Transition)	Turbulent	Non-Turbulent	Turbulent	Non-Turbulent		
Non-Turb Components (Sec)	0.0000	0.0000	0.0000	6.0000		
Turbulent Components (Sec)	0.1637	0.0000	8.1842	0.0000		
					6.00	Non Turb
					8.35	Turbulent

FIG. X1.5 Liquid Sample
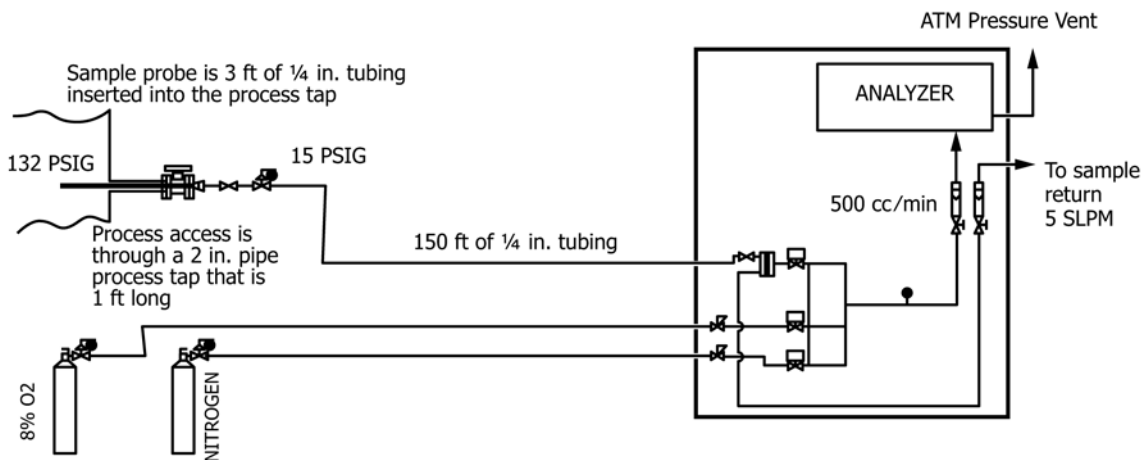
FIG. X1.6 Non-Turbulent Gas Sample

	Process Tap	Tap Sam Cond	Sample Transport	Analyzer Sam Sys	Lagtimes	
					seconds	
Molecular weight of sample gas	30	30	30	30		
Temperature of sample gas, °C	25	25	25	25		
Approximate gas density (lbs/cf)	0.7637	0.7637	0.1546	0.1546		
Viscosity of sample gas (cP)	0.0171	0.0171	0.0171	0.0171		
Reynolds Number	1829	NA	1829	NA		
Pressure (PSIG)	132	132	15	15	24.12	1 Purge 75%R
L (feet)	3.0000	NA	150.0000	NA	48.24	2 Purge >93%R
ID (inches)	0.1800	NA	0.1800	NA	72.36	3 Purge >97%R
Flow (SLPM)	5.0000	5.5000	5.5000	0.5000	96.48	4 Purge >98%R
Volume (litres)	0.0150	0.0100	0.7502	0.0200		
Pressure corrected purge volume	0.1497	0.0998	1.5157	0.0404		
Single Purge Time (seconds)	1.6335	1.0887	16.5354	4.8490		
Average Velocity (FPS)	1.8365	NA	9.0714	NA		
Flow Type (w/o Transition)	Non Turbulent	Non Turbulent	Non Turbulent	Non Turbulent		
Non-Turb Components (Sec)	1.6335	1.1000	16.5354	4.8500	24.12	
Turbulent Components (Sec)	0.0000	0.0000	0.0000	0.0000	0.00	

FIG. X1.6 Non-Turbulent Gas Sample

ADDITIONAL READING

(1) Clevett , Kenneth J., *Process Analyzer Technology*, Wiley-Interscience, New York, 1986.

(2) Crane Company Engineering Department, Flow of Fluids through Valves, Fittings, and Pipes, Technical Paper No. 410, New York, 1986.

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(4) Green, Don W., editor, *Perry's Chemical Engineer's Handbook*, Sixth Edition, McGraw-Hill Book Company, New York, 1984.

(5) McMillan, Gregory K., and Considine, Douglas M., *Process Instruments and Controls Handbook*, 5th Edition, McGraw-Hill Professional, New York, 1999.

(6) Sherman, R. E., editor, *Analytical Instrumentation*, Instrument Society of America, Research Triangle Park, 1996.

SUMMARY OF CHANGES

Subcommittee D02.25 has identified the location of selected changes to this standard since the last issue (D7278 – 11) that may impact the use of this standard. (Approved April 1, 2016.)

(1) Revised subsection 6.1 and added new subsection 6.2.1.1.