Standard Practice for Sampling Steam[1]

This standard is issued under the fixed designation D 1066; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice covers the sampling of saturated and superheated steam. It is applicable to steam produced in fossil fired and nuclear boilers or by any other process means that is at a pressure sufficiently above atmospheric to establish representative sample flow. It is also applicable to steam at lower and subatmospheric pressures for which means must be provided to establish representative flow.

1.2 For information on specialized sampling equipment, tests or methods of analysis, reference should be made to the *Annual Book of ASTM Standards*, Vols 11.01 and 11.02, relating to water.[2,3]

1.3 The values stated in either inch-pound units or SI units are to be regarded as standard. Within the text, the inch-pound units are shown in parentheses. The values stated in each system are not exact equivalents. Therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with this specification.

1.4 *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:*

A 269 Specification for Seamless and Welded Austenitic Stainless Steel Tubing for General Service[4]

A 335/A 335M Specification for Seamless Ferritic Alloy-Steel Pipe for High Temperature Service[4]

D 1129 Terminology Relating to Water[3]

D 3370 Practices for Sampling Water in Closed Conduits[3]

D 5540 Practices for Flow Control and Temperature Control for On-Line Water Sampling and Analysis[3]

3. Terminology

3.1 *Definitions*:

3.1.1 For definitions of terms used in this practice, refer to definitions given in Practice D 1129.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *isokinetic sampling*—a condition wherein the velocity of the sample entering the port or ports of the sample nozzle(s) is the same as the velocity in the stream being sampled.

3.2.2 *sample cooler*—a small heat exchanger designed to provide cooling/condensing of small process sampling streams of water or steam.

3.2.3 *sampling*—the withdrawal of a representative portion of the steam flowing in the boiler drum lead or pipeline by means of a sampling nozzle and the delivery of this portion of steam in a representative manner for analysis.

3.2.4 *saturated steam*—a vapor whose temperature corresponds to the boiling water temperature at the particular existing pressure.

3.2.5 *superheated steam*—a vapor whose temperature is above the boiling water temperature at the particular existing pressure.

4. Summary of Practice

4.1 This practice describes the apparatus, design concepts and procedures to be used in extracting and transporting samples of saturated and superheated steam. Extraction nozzle selection and application, line sizing, condensing requirements and optimization of flow rates are all described in detail. Condensed steam samples should be handled in accordance with Practices D 3370 and D 5540.

5. Significance and Use

5.1 It is essential to sample steam representatively in order to determine the amount of impurities, including moisture, in it. An accurate measure of the purity of steam provides information, which may be used to determine whether the purity of the steam is within necessary limits to prevent damage or deterioration of subsequent equipment, such as turbines, etc. Impurities in the steam may be derived from

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[1] This practice is under the jurisdiction of ASTM Committee D19 on Water , and is the direct responsibility of Subcommittee D19.03 on Sampling of Water and Water-Formed Deposits, Surveillance of Water and Flow Measurement of Water Samples.

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[2] *Annual Book of ASTM Standards*, Vol 11.01.

[3] *Annual Book of ASTM Standards*, Vol 11.02.

[4] *Annual Book of ASTM Standards*, Vol 01.01.

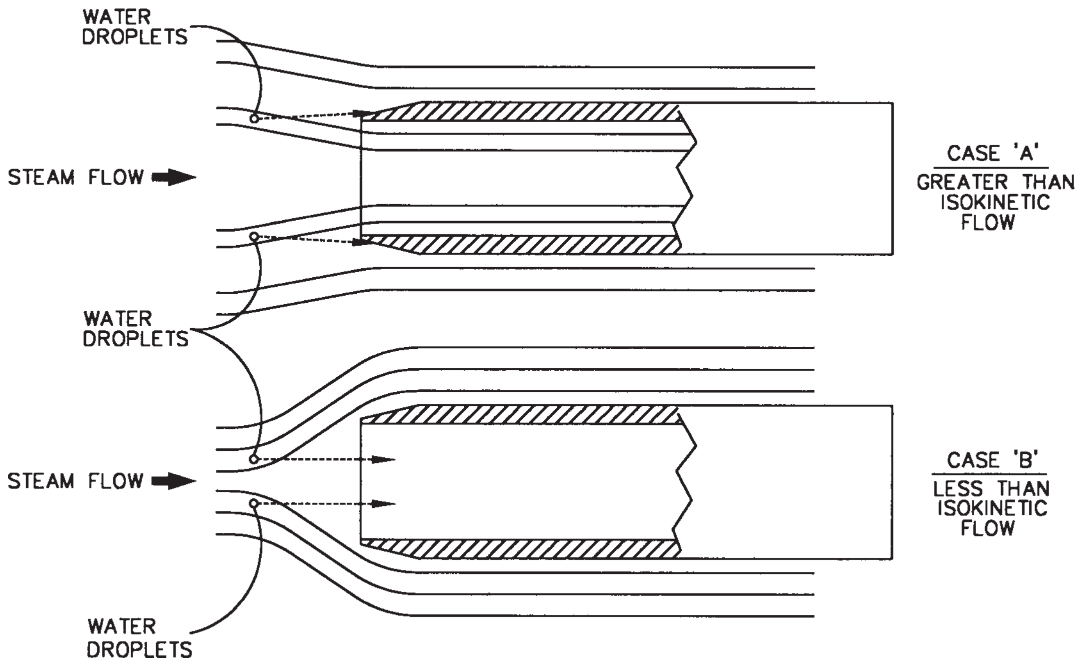


FIG. 1 Effect of Nono-Isokinetic Sampling

boiler water carryover, inefficient steam separators, natural salt solubility in the steam and other factors.

6. Interferences

6.1 *Saturated Steam*— Sampling of steam presents difficult extraction and transport problems that affect the representativeness of the sample.

6.1.1 Isokinetic sampling requires that the velocity of the fluid entering the sample nozzle port(s) is the same as the velocity of the stream being sampled at the location of the sample nozzle. When the sample is not extracted isokinetically the contaminants in the steam are not properly represented in the sample. The effects of non-isokinetic sampling are illustrated in Fig. 1 and can make the sample unrepresentative.

6.1.2 Traditionally, saturated steam samples with initial steam velocities above 11m/s (36f/s) were considered to provide adequate turbulent flow to ensure transport of most particulates and ionic components. More recent studies **(1)(2)**[5] find that because many sample lines are long and uninsulated, steam samples are frequently fully condensed prior to reaching the sample station. Partially or fully condensed samples usually have a velocity too low to prevent excessive deposition and the sample becomes nonrepresentative of the source. Detailed design of the sample line to control vapor and liquid velocity can minimize this interference but cooling of saturated steam samples at the source is recommended to assure a representative sample. See Practice D 3370 for further information on factors that affect liquid sample transport.

6.2 *Superheated Steam*—Most contaminants can be dissolved in superheated steam. However as steam pressure and temperature are reduced the solubility of many contaminants is decreased and the contaminants deposit on the inner surfaces of the sample line **(3)**. This condition has been found to be prevalent only in regions of dry wall tube where the temperature of the tube wall exceeds the saturation temperature of the steam.

6.2.1 Interference also occurs when the transport tube temperature is at or below the saturation temperature. The steam loses superheat and dissolved contaminants deposit on the tube wall. The sample is no longer representative. Superheated steam samples shall be cooled or desuperheated in the sample nozzle or immediately after extraction to ensure a representative sample. See 7.1.3.3 and 7.2.4.

7. Materials and Apparatus

7.1 *Extracting the Sample*:

7.1.1 *Saturated Steam*— Since saturated steam is normally sampled as a two-phase fluid, made up of steam and small droplets of water, isokinetic sampling shall be employed. Since steam velocities vary with boiler load it normally is not practical to sample isokinetically throughout the load range. Normally, the load of interest is full load or a guaranteed overload. The sampling system shall be designed to provide isokinetic sampling at this design load.

7.1.1.1 At low velocities, the moisture in wet steam forms a film along the inside surface of the steam line that entrains impurities **(4)**. Table 1 shows the minimum steam flow required for representative samples at various steam pressures.

7.1.2 *Superheated Steam*—Superheated steam is usually regarded as a single phase fluid. Unless particulates are being measured, isokinetic sampling is not required. Most impurities in superheated steam are present in vaporous form and are thoroughly mixed with the steam vapor. However, an oxide layer forms on the steam side of superheater and reheater lines and gets thicker with increased service. Since the physical properties of the oxide are different from the parent metal,

[5] The boldface numbers given in parentheses refer to a list of references at the end of this standard.

TABLE 1 Minimum Saturated Steam Line Conditions at Point of Sampling

Saturated Steam Pressure		*Minimum Steam Flow*	
psig	(kPa)	ft/s	(m/s)
100	(690)	195	(59.6)
200	(1379)	141	(42.8)
300	(2068)	114	(34.8)
400	(2758)	95	(29.1)
500	(3447)	83	(25.3)
700	(4826)	70	(21.2)
1000	(6895)	54	(16.6)
1500	(10342)	36	(11.0)
2000	(13790)	26	(7.9)
2500	(17237)	18	(5.5)
2800	(19300)	13	(4.1)

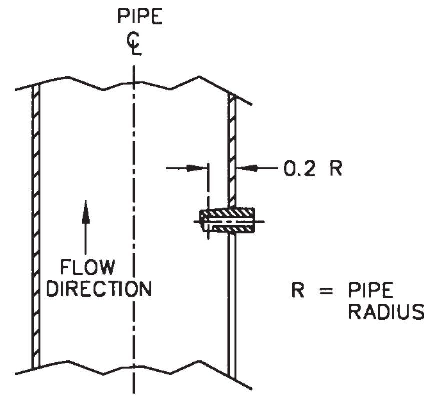


FIG. 2 Single Port Nozzle

changing pressure and temperature cause the oxide layer to crack and exfoliate **(3)**. The exfoliated material can retain significant amounts of impurities, such as sodium, which can be leached into the sample when the material contacts the liquid phase of the sample **(5) (6)**.

7.1.2.1 Because the dissolved contaminants in high pressure superheated steam deposit on the inner surfaces of the nozzle and sample lines as the sample desuperheats, superheated steam samples shall be rapidly desuperheated or condensed near the point of extraction. See 7.2.4.

7.1.3 *Sampling Nozzles*— Stratification of suspended solids in horizontal steam pipes can influence the composition of the steam samples. To minimize the effects of stratification it is recommended that steam sampling nozzles be located in long vertical pipes. To ensure that all water droplets are carried in the flow stream, downward flow is preferred. Nozzles which must be located in a horizontal pipe should be near the top of the pipe **(1)**. Sampling nozzles can be either of a single port or multiport configuration as specified or recommended by the boiler manufacturer or design engineer.

7.1.3.1 *Single Port Nozzles*—A single port nozzle which is positioned at a known distance from the inner surface can also be used when it is at a location where a predictable velocity gradient exists. Normally this would be at a location where fully developed turbulent flow exists which enables the determination of velocity at any location in the steam line. Single port nozzles are most frequently located at a distance from the pipe wall where the actual velocity equals the average velocity, typically 0.2 R of the pipe **(1)(6)**. Fig. 2 depicts this typical single port nozzle. This type of single port nozzle can be easy to install and provides good results at a reasonable cost. Fig. 3 shows another single port nozzle used to sample saturated steam in superheater supply tubes.

7.1.3.2 *Multi-Port Nozzles*—Multi-port nozzles which sample at various locations across the pipe cross section can also be used. These nozzles may be used only at locations where the velocity profile across the pipe can be determined **(1)**. Ports shall be located so that each port samples from an equal fraction of the cross-sectional area of the pipe being sampled. Since the steam velocity varies across the pipe section, each port diameter must be sized to result in isokinetic sampling with the proper fraction of sample collected from each port. Table 2 and Fig. 4, Fig. 5, and Fig. 6 detail information on port location, port sizing and internal passage sizing for multi-port nozzles.

7.1.3.3 *Sampling Nozzles for Superheated Steam*—The nozzles described for use with saturated steam can also be used for superheated steam. However, isokinetic sampling is normally not required for superheated steam unless particulates are measured.

7.1.3.4 In order to minimize the deposition of contaminants from superheated steam several experts currently recommend injecting condensed and cooled sample directly into the superheated steam sampling nozzle **(1)**. Due to concern for induced thermal stresses, few power plants have installed nozzles with integral condensate injection. An acceptable alternative is to condense the sample immediately after extraction. See 7.2.4 for sample line and condensing design criteria.

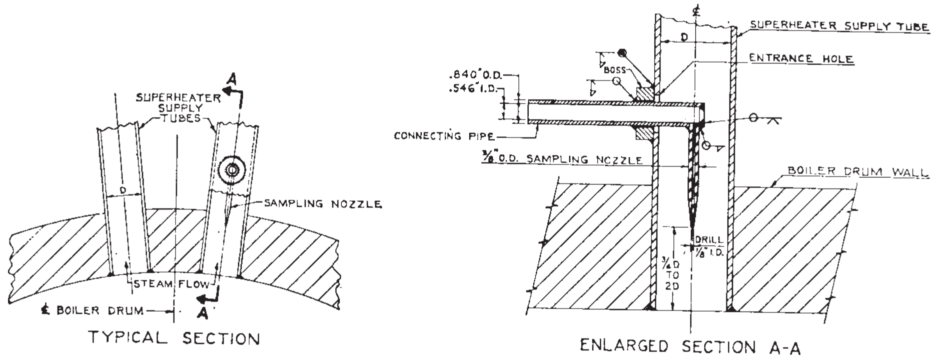
7.1.3.5 *Materials and Installation*—Sampling nozzles shall be adequately supported and shall be designed to prevent failure due to flow-induced vibration, thermal stress cycling and other possible causes. Nozzles are most often made of AISI 316 **(7)** or other austenitic stainless steel or alloy 600 **(1)(6)**. Weld joints used for dissimilar metals are subject to high thermal stresses due to different coefficients of thermal expansion. Care should be used in weld rod selection and inspection of all dissimilar metal weld joints.

7.1.3.6 Sample ports shall be drilled cleanly, using the standard drill size nearest to the calculated port diameter. The port inlet ends shall not be chamfered or rounded, and the outlet ends shall be free of burrs. The smallest recommended port diameter is 3.18 mm (1⁄8) in. Port diameters of less than 2.38 mm (3⁄32) in. are subject to plugging and shall not be used. Total port area shall be determined to maintain isokinetic sampling in the nozzle port(s) at the desired sampling rate and design steam load.

7.1.3.7 At least one shut off valve (commonly referred to as a root valve) shall be placed immediately after the point from which the sample is withdrawn so that the sample line may be isolated. In high pressure applications two root valves are often used. The valve(s) selected should be rated for the pressure/temperature of the sample source.

7.2 *Transporting the Sample*:

7.2.1 *General*—Sample lines should be designed so that the sample remains representative of the source. See 6.1 and 7.1.1.



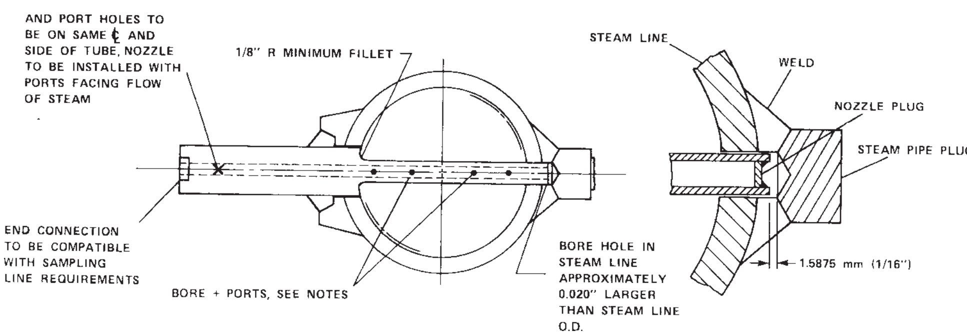
NOTE 1—Sampling nozzle shall be centered on superheater supply tube.

FIG. 3 Steam Sampling Nozzle, Single-Port Type

TABLE 2 Calculations for Steam Sampling Nozzles for Lines 6 in. (152 mm) and Larger, Equal Size Ports, Unequally Spaced

Nominal pipe size		________	in.	________	cm
D_o	= Pipe OD	________	in.	________	cm
D_1	= Pipe ID	________	in.	________	cm
T	= Pipe wall thickness	________	in.	________	cm
N	= Total number of ports	________			
Radii of port circles:					
	$r_1 = (D_1/2)\sqrt{1/N}$	________	in.	________	cm
	$r_2 = (D_1/2)\sqrt{3/N}$	________	in.	________	cm
	$r_3 = (D_1/2)\sqrt{5/N}$	________	in.	________	cm
F	= Flow rate of fluid through pipe	________	lb/h	________	m/s
f	= Flow rate of total sample extracted	________	lb/h	________	m/s
A	= Traverse area of pipe = $0.7854\ D_1^2$	________	in.^{2}	________	cm^2
a	= Total port area = Af/F	________	in^2	________	cm^2
d	= Diameter of ports = $\sqrt{a/0.7854N}$	________	in.[A]	________	cm
		Use ____	drill	Use ____	drill
b	= Diameter of nozzle bore = $\sqrt{3a/1.5708}$	________	in.	________	cm
		Use ____	drill	Use ____	drill

[A] Port diameter shall be not less than 0.0625 in. To increase the port diameter, increase the flow rate of sample extracted, or if this is not practical, decrease the number of ports.



NOTE 1—The design, materials, construction, welds, heat treatment, and non-destructive test requirements shall be in accordance with all applicable codes. The dimensions given are only a guide and should be checked for each case.

NOTE 2—For actual inside pipe diameters of 51 mm (2 in.) to 152 mm (6 in.) inclusive, the number of sampling ports shall be four (4).

NOTE 3—Sampling ports shall be cleanly drilled, using a drill of proper size. The entrance end shall not be chamfered. The bore of the sampler shall be reamed after ports are drilled to insure that all burrs are removed.

NOTE 4—The bore of the nozzle and tap size of the ports shall be in accordance with calculated data (Fig. 6). The ports shall face steam flow, and the diameter of each port shall not be less than 1.5875 mm (1⁄16 in.).

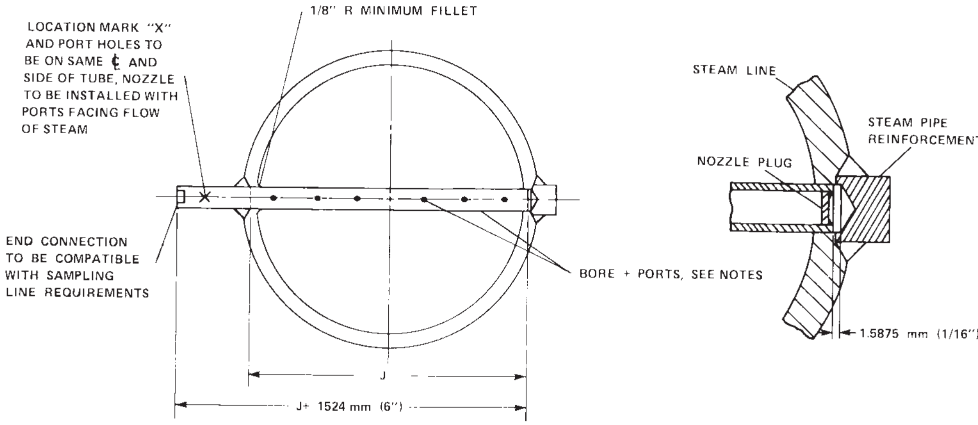
NOTE 5—As a guideline, the first mode natural frequency of vibration of the sampling nozzle should be at least 25 % above the exciation frequency.

NOTE 6—The sampling nozzle shall not occupy more than 25 % of the cross-sectional area of the steam pipe.

FIG. 4 Steam Sampling Nozzle, Multiport Type for Line Internal Diameters from 51 mm (2 in.) through 152 mm (6 in.)

They shall be as short as feasible and of the smallest practicable bore to facilitate flushing, minimize conditioning requirements, reduce lag time and changes in sample composition, and provide adequate velocity and turbulence. The designer is responsible for ensuring that applicable structural integrity requirements are met to prevent structural failure. Small tubing is vulnerable to mechanical damage and should be protected.

7.2.1.1 Traps and pockets in which solids might settle shall be avoided, since they may be partially emptied with changes in flow conditions and may result in sample contamination.



J		NOZZLE OD	
mm	INCHES	mm	INCHES
1412.8 – 3397.2	5-9/16 – 13-3/8 INCL.	266.7	1.05 x x HEAVY PIPE
3413.1 – 5143.5	13-7/16 – 20-1/4 INCL.	381	1.5
5159.4 – 7270.7	20-5/16 – 28-5/8 INCL.	508	2.0
7286.6 – 9144.0	28-11/16 – 36 INCL.	635	2.5

NOTE 1—The design, materials, construction, welds, heat treatment, and non-destructive test requirements shall be in accordance with all applicable codes. The dimensions given are only a guide and should be checked for each case.

NOTE 2—Sampling ports shall be cleanly drilled, using a drill of proper size. The entrance end shall not be chamfered. The bore of the sampler shall be reamed after ports are drilled to insure that all burrs are removed.

NOTE 3—The bore of the nozzle and tap size of the ports shall be in accordance with calculated data (Fig. 6). The ports shall face steam flow, and the diameter of each port shall not be less than 1.5875 mm (0.0625 in.).

NOTE 4—As a guideline, the first mode natural frequency of vibration of the sampling nozzle should be at least 25 % above the exciation frequency.

NOTE 5—Insert sample probe into steam line so that probe penetrates hole on opposite side to proper depth. Check penetration by measuring through plug hole from outside of steam line or top of weld path to end of probe.

NOTE 6—Insert plug until probe is reached, withdraw 1.5875 (1⁄16 in.) and weld to steam line.

NOTE 7—The sampling nozzle shall not occupy more than 25 % of the cross-sectional area of the steam pipe.

FIG. 5 Steam Sampling Nozzle, Multiport Type for Line Internal Diameters Larger than 152 mm (6 in.)

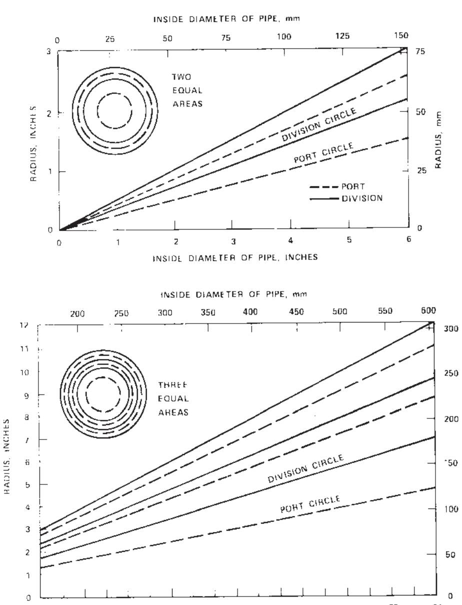


FIG. 6 Radii of Circles for Dividing a Circular Pipe into Annuli of Equal Areas

Sample tubing shall be shaped so that sharp bends, dips, and low points are avoided, thus preventing particulates from collecting. Expansion loops or other means shall be provided to prevent undue buckling and bending when large temperature changes occur. Such buckling and bending may damage the lines and allied equipment. Routing shall be planned to protect sample lines from exposure to extreme temperatures.

7.2.2 *Materials*—The material from which the sample lines are made shall conform to the requirements of the applicable specifications as follows: Specification A 335 for pipe and Specification A 269 for tubing.

7.2.2.1 For sampling steam, the sampling lines shall be made of stainless steel that is at least as corrosion resistant as 18 % chromium, 8 % nickel steel (AISI 304 or 316 austenitic stainless steels are commonly used **(7)**).

7.2.3 *Saturated Steam*— Many power generating stations cool their steam samples at a central sampling station, most frequently located in the chemistry laboratory. This practice has resulted in many sampling lines exceeding 400 ft (120 m) in length and in samples being unrepresentative of the source. This method requires strict adherence to detailed design of the sample line to maintain condensed liquid sample velocity. See 7.2.3.1 and 7.2.3.2. The preferred method to sample saturated steam is to condense the sample as near to the source as is possible then size the condensate portion of the line to maintain the recommended liquid velocity in accordance with Practice D 3370.

7.2.3.1 *Long Steam Sample Line Phenomena*—A saturated steam sample originates at the sampling nozzle as vapor with entrained liquid droplets **(2)**. As flow proceeds down the tube, heat loss from the outside tube surface causes a liquid film to form on the inside surface of the tube. The liquid film moves down the tube at significantly slower velocity than the steam vapor. The surface of the liquid has moving waves that vary with the liquid and vapor velocities. If the steam velocity is sufficiently high then droplets of liquid are entrained into the moving steam from the wave crests. Simultaneously droplets carried by the steam flow impinge on the liquid film and become entrapped in it. The film thickness gradually increases with additional condensation. When the film reaches sufficient thickness the flow develops to slug or churn flow where large bubbles of steam flow faster than the accompanying liquid and bypass the liquid between the bubbles. Gradually the size of the bubbles decreases until all steam condenses and single phase liquid flow results. If the sample line is short then all phases may not be encountered **(2)**. The term ′condensing length' refers to the length of tube where the entire steam sample has condensed.

7.2.3.2 A second scenario can also occur with saturated steam samples. When the steam velocity entering the sample line is high, then pressure drop can alter the flow characteristics of the sample. High steam velocity is accompanied by high pressure drop. The high pressure drop results in expansion of the steam which causes higher steam velocity with higher incremental pressure drop. This condition causes a compounding effect of both increased velocity and increased pressure drop. Depending upon the steam pressure a saturated steam sample can deviate from the saturation curve and enter the superheat region. These conditions do not normally exist at pressures above 500 psig (35 Bar). Combined cycle plants with multiple pressure heat recovery steam generators typically produce steam at pressures less than (35 Bar) 500 psig. These samples will experience extremely high pressure drop, which can be maintained only for shorter sample tube lengths (typically less than 200 ft (60 m)), unless the inside diameter of the sample line is adequately sized for the pressure. See 8.2.1.

7.2.3.3 *Steam Sample Line Sizing*—Sample lines for saturated steam can best be designed by using computer programs because of the multiple iterations required to optimize the line size(s). The computer programs can determine heat loss and pressure drop for any flow condition. It can then determine changes resulting from expansion or differing flow regimes in a two phase flow model. This sizing is critical to obtaining a representative sample[6].

7.2.3.4 *Sample Flow Rate*— A change in flow rate of a saturated steam sample results in a change in velocity at the steam inlet proportional to the change in flow rate. However, it also produces a change in the condensing length. The various regions of two phase flow then shift along the sample line. Areas of tubing that are liquid at one flow rate have two phase flow at a higher flow rate. Calculations show that flow rate changes of about 10 % can cause velocity changes by a factor of two or three in regions near the fully condensed length. This region experiences ′slug' flow with fluctuating velocities which tends to scrub previously deposited material from the wall. Similarly decreased flow reduces the condensing length with liquid flow occupying portions of tubing which previously had ′slug' or ′bubbly' flow. Therefore, constant sample line flow should be maintained or results should be interpreted accordingly.

7.2.4 *Superheated Steam*—Superheated steam samples originate at the sample source as a single phase fluid with dissolved contaminants. See 6.2 for a detailed discussion of the problems in getting representative superheated steam samples. To minimize loss of contaminants superheat shall be removed in the sample nozzle or the sample condensed immediately after extraction. If the sample is condensed immediately after extraction, the sample cooler must be sized to fully condense and sub cool the sample to avoid the potential to reheat the sample above saturation as it flows through downstream sample tubing. Also, the sample line and exterior appurtenances of the sample nozzle, must be insulated to avoid any desuperheat prior to condensation of the sample. Note: if the sample is only desuperheated it will behave in the same manner as saturated steam samples discussed previously until fully condensed.

7.3 *Sample Cooler or Condenser*:

7.3.1 Sample coolers or condensers used for steam sample condensation should be capable of reducing the incoming sample temperature to within 10°F (5.6°C) of the cooling water inlet temperature at sample flows that are sufficient to provide a representative sample. See 6.1, 7.1.1 and 7.2.3. Cooling water requirements should be as low as possible to minimize water consumption, therefore high efficiency sample coolers are recommended. The tube through which the sample will flow shall be one continuous piece and shall extend completely through the cooler without deformation and so there is no possibility of sample contamination or dilution from the cooling water. The tube shall be of sufficient strength to withstand the full pressure and temperature of the steam being sampled.

7.3.2 The cooler or condenser tube shall be made of stainless steel that is at least as corrosion resistant as 18 % chromium - 8 % nickel steel. Specific water chemistry could dictate different materials for improved corrosion resistance, for example, Alloy 600 for high chlorides. The diameter of the tube shall be as small as practicable based on representative sample flows so that storage within the coil is low and the time lag of the sample through the cooler is minimal. See Practice D 3370 for further information on sample coolers.

8. Other Requirements

8.1 When sampling saturated steam from a boiler drum or header arranged with multiple tubular connections to a superheated header, samples shall be taken from selected tubes at regularly spaced points. A single-port sampling nozzle installed in individual tubes (see Fig. 3) is preferable to the multi-port

[6] A two phase flow computer program developed by Sentry Equipment Corp. has been found suitable for this purpose.

nozzle. Some boiler manufacturers provide internal sample collection piping to facilitate steam drum sampling **(1)**.

8.2 When the steam to be sampled is at a pressure high enough above atmospheric pressure (typically 35 Bar (500 psig)) to provide an adequate sample flow rate, the extraction of the sample usually presents no problem. At lower and subatmospheric pressures, special provisions may be required to establish sample flow and to deliver a flowing or batch sample. Several methods of providing sample flow may be employed as follows:

8.2.1 *Low Pressure Steam Samples*—Due to the significant difference in the density of steam at lower pressures, substantially greater velocities with accompanying pressure drop can occur in the sample transport piping/tubing. Care must be taken to properly size the transport piping/tubing to avoid excessive pressure drop. See 7.2.3.1. Steam samples from boilers used for industrial processes, utility boiler reheaters, and intermediate and low pressure steam drums in combined cycle heat recovery steam generators usually present difficult transport problems. For steam samples at pressures below 20 Bar (300 psig), the sample shall be condensed near the source and either analyzed there or pumped to a central analyzing location.

8.2.2 *Atmospheric and Subatmospheric Steam Samples*—A small sample pump capable of low net positive suction head (NPSH) may be used to draw these types of steam samples through a sample cooler to condense it prior to being pumped to a sample container or analytical instrument. Care should be taken in selecting the wetted materials of the pump and its sealing mechanism to avoid contamination of the sample. See Practice D 3370. Other methods of withdrawing the sample to draw it through the sample cooler can also be acceptable, for example, ejector. It is virtually impossible to assure representative sample velocities for these conditions.

9. Keywords

9.1 isokinetic sampling; sample cooler; sampling; sampling nozzles; saturated steam; superheated steam

REFERENCES

(**1**) Coulter, E., “Sampling Steam and Water in Thermal Power Plants,” Electric Utility Workshop, University of Illinois, March 1988.

(**2**) Rommelfaenger, E., “Design Criteria for Steam Sample Lines”, presented at *EPRI Fourth International Conference on Cycle Chemistry in Fossil Plants*, September 1994.

(**3**) Stringer, J., “Steamside Oxidation and Exfoliation”, McMaster University, May 4–5, 1983.

(**4**) Goldstein, P. and Simmons, F.B., “An Experimental Investigation of Factors Which Influence the Accuracy of Steam Sampling-Series II”, *Proceedings of the American Power Conference*, Vol. XXVI, 1964.

(**5**) Cobb, R.V., and Coulter, E.E., “The Prevention of Errors in Steam Purity Measurement caused by Deposition of Impurities in Sampling Lines”, *Proceedings of the American Society for Testing and Materials*, Vol 61, 1961, pp 1386–1395.

(**6**) Jonas, O., Mathur, R. K., Rice, J.K., and Coulter, E.E., “Development of Steam Sampling”, *EPRI Research Project 2712–8*, June 1991.

(**7**) *Steel Products Manual: Stainless and Heat Resisting Steels*, American Iron and Steel Institute, December 1974.

(**8**) *Guideline Manual on Instrumentation and Control for Fossil Plant Cycle Chemistry* , Electric Power Research Institute, April 1987, EPRI CS-5164.