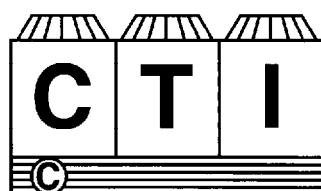


COOLING TOWER INSTITUTE

Isokinetic Drift Test Code



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This guideline document summarizes the best current state of knowledge regarding the specific subject. This document represents a consensus of those individual members who have reviewed this document, its scope and provisions. It is intended to aid all users or potential users of cooling towers.



PART I

TEST PROCEDURE

1.0 SCOPE AND PURPOSE

1.1 Scope. This code describes the measurement of drift emissions from water-cooling towers using isokinetic methods.

1.2 Purpose. The purpose of this Code is to describe instrumentation and procedures for the testing and evaluation of drift from water-cooling towers.

1.2.1 Overview. In the operation of an evaporative cooling tower, moving air contacts water for heat transfer. The circulating water is distributed as droplets or films to maximize the surface area exposed to the air. In these processes, small water droplets are entrained in the air moving through the tower. Droplets that are not removed from the air stream are exhausted from the cooling tower into the environment. These droplets, which possess the same minerals (but not necessarily in the same concentrations) as the circulating water, are known as drift.

Cooling tower exit air contains water vapor, drift droplets, condensate droplets and particulate which originates in the ambient air but is unscrubbed by the cooling tower. The proportion of these constituents in the exit air are regulated by a number of factors including, but not limited to, drift eliminator design and installation, water distribution and fill system design, ambient psychrometric and wind conditions, circulating water chemistry, etc.

Cooling tower drift measurements are required for laboratory research and field measurement of drift emission rates. The impetus behind such measurements usually falls into one of three categories.

- a) Drift acceptance testing
- b) Environmental impact assessment and modeling
- c) Status testing on existing cooling towers.

If drift measurements are conducted to verify performance for contractual drift guarantees, it is emphasized that the guarantee basis is for drift only, and the guarantee is independent of the influence of ambient air constituents. Ambient air constituents that are drawn into the tower and then escape via the exit air stream may bias drift measurements. This requires that the drift measurement and calculation analysis method remain independent of significant influence of elements found in the inlet air stream. Background constituent levels cannot be subtracted from outlet levels since the scrubbing effect of the cooling tower is unknown.

1.2.2 There are two basic methods of drift measurement - Isokinetic (IK) for drift rate measurement and Sensitive Surface (SS) for drift droplet size characterization. Each method yields specific information regarding the drift characteristics of the tower. Table 1 characterizes each method.

TABLE 1

Comparison of Isokinetic and Sensitized Surface Drift Measurements

ISOKINETIC METHODS (IK)

POSITIVE ATTRIBUTES

1. High collection efficiency on all droplet sizes.
2. Analysis for specific elements possible.
3. Provides integrated sample over exit area.

NEGATIVE ATTRIBUTES

1. Airborne elements may bias results.
2. Long sample times required for high efficiency drift eliminators or low mineral concentrations.

SENSITIZED SURFACE METHODS (SS)

POSITIVE ATTRIBUTES

1. Provides droplet size characteristics above 30 μm .
2. Not effected by airborne elements.
3. Provides relative indication of drift eliminator effectiveness.

NEGATIVE ATTRIBUTES

1. Poor collection efficiency on small droplets less than 30 μm .
2. Can not distinguish between condensation and drift.
3. No droplet analysis for specific constituents.

1.2.3 This Code describes a Heated Bead Isokinetic (HBIK) Drift Test Procedure. However, an alternative Isokinetic Procedure with demonstrated performance may be utilized, if mutually agreed to by all parties.

1.3 Flexibility. It is recognized that the data limitations specified throughout this test procedure represent desired conditions which may not exist at the time the test is performed. In such cases, existing conditions may be used if mutually agreed upon prior to the test by authorized representatives of the manufacturer, the purchaser and the CTI.

1.4 Other Uses. Although intended primarily for drift acceptance testing, all or parts of this Code may be used for other purposes, such as the determination of mineral mass emission.

1.5 Impartial Testing Service. The CTI Representative referred to in this Code shall be an impartial party to the test and shall have no connection with the manufacturer, the purchaser, or the Cooling Tower Institute, other than a contractual agreement with the latter. This Representative shall be sufficiently qualified to ensure that measurements and evaluations are made in accordance with the Code. The CTI Representative is hereinafter referred to as the CTI.

1.6 Nomenclature.

The symbols used in this Code are identified in the Table 2.

TABLE 2
Nomenclature

Symbol	Description	Units			
A_N	Area of intake nozzle on isokinetic device. sampling	$m^2, (ft^2)$	P_M	Absolute pressure of air sample entering the flow rate measuring device.	kPa, (in Hg)
A_{SP}	Area of the sampling plane.	$m^2, (ft^2)$	Q_{ACT}	The total volumetric air flow rate at the sampling plane.	L/s, (ft ³ /sec)
C_P	Coefficient of Pitot tube used for measurement of air velocity pressure.	Dimensionless	Q_{mi}	Volumetric flow rate of air at sampling point i as indicated by the measuring device.	L/s, (ft ³ /sec)
$C_{S(STD)}$	Concentration of minerals collected by sampling device expressed as weight per unit volume of air at <u>standard dry</u> conditions.	g/L, (g/ft ³)	Q_{STD}	Volumetric flow rate of dry air at sampling plane, corrected to standard air.	L/s, (ft ³ /sec)
C_{TC}	Concentration of tracer element in circulating water.	mg/L(ppm)	Q_{si}	Volumetric flow rate of air entering the sampling nozzle positioned at point i.	L/s, (ft ³ /sec)
$D\%$	Drift rate expressed as a percentage of the circulating water flow rate.	Dimensionless	Q_{WT}	Mass flow rate of circulating water entering the cooling tower at measured test conditions.	L/s, (gpm)
E_R	Emission rate of sample tracer	g/s, (lb/hr)	R	Cooling Range	°C, (°F)
G	Mass flow rate of dry air through the cooling tower.	kg/s, (lb/hr)	T_{CW}	Temperature of cold water leaving the cooling tower.	°C, (°F)
G_D	Mass flow rate of dry air through the cooling tower at design operating conditions	kg/s, (lb/hr)	T_{DB}	Dry-bulb temperature	°C, (°F)
G_T	Mass flow rate of dry air through the cooling tower at measured test conditions	kg/s, (lb/hr)	T_{HW}	Temperature of hot water entering the cooling tower.	°C, (°F)
L	Mass flow rate of circulating water entering the cooling tower.	kg/s, (lb/hr)	T_M	Average temperature of air sample entering the air flow rate measuring device.	°C, (°F)
L_D	Mass flow rate of circulating water entering the cooling tower at design operating conditions.	kg/s, (lb/hr)	T_S	Temperature of air entering the sampling nozzle.	°C, (°F)
L/G	Ratio of mass flow rate of water to that of air.	Dimensionless	T_{WB}	Wet-Bulb Temperature.	°C, (°F)
$(L/G)_D$	Ratio of mass flow rate of water to that of air at design operating conditions.	Dimensionless	$t_{1,i}$	Nominal sampling time (duration) at point i.	s, (sec)
$(L/G)_T$	Ratio of mass flow rate of water to that of air at measured test conditions.	Dimensionless	$t_{2,i}$	Sampling time (duration) at point i adjusted for angularity of the flow θ .	s, (sec)
M_D	The molecular weight of dry air at the flow rate measuring device	kg/kg-mole (lb/lb-mole)	t_E	Total equivalent sampling time $t_E = t_{1,i} * N$	s, (sec)
M_F	Mole fraction of dry air.	kg/kg-mole, (lb/lb-mole)	$U_{s,i}$	Velocity of air at sample point i.	m/s, (ft/sec)
M_S	The molecular weight of moist air at the sampling plane.	kg/kg-mole, (lb/lb-mole)	$U_{x,i}$	Velocity of air normal to sampling plane at point i.	m/s, (ft/sec)
N	The number of sample points.	Dimensionless	$U_{x(avg)}$	Average velocity of air normal to the sampling plane.	m/s, (ft/sec)
P_B	Barometric pressure at the test site.	kPa, (in Hg)	V_I	Initial reading of dry gas meter.	L, (ft ³)
P_S	Absolute pressure of air at the sampling plane.	kPa, (in Hg)	V_F	Final reading of dry gas meter.	L, (ft ³)
			V_{LC}	Total mass of moisture collected in sampler.	g
			V_M	Total volume of air measured by dry gas meter.	L, (ft ³)
			$V_{M(STD)}$	Total volume of air measured by dry gas meter, adjusted to standard conditions.	L, (ft ³)

$V_{M,i}$	Volume of air measured by dry gas meter over duration of sampling at point i in the sampling plane.	L, (ft ³)
$V_{S,i}$	Required volume of air taken at point i in the sampling plane.	L, (ft ³)
$V_{WC(STD)}$	Volume of water vapor collected, adjusted to standard conditions.	L, (ft ³)
W_T	Net weight of tracer.	mg
$W_{S,i}$	Water vapor content from CTI Cooling Tower Manual, Chapter 5, Table 23	Dimensionless
Y	Meter correction factor	Dimensionless
% CO ₂	Percentage of carbon dioxide, by volume, dry.	Dimensionless
% H ₂ O	Percentage of moisture by volume.	Dimensionless
% I	Percentage isokinetic.	Dimensionless
% N ₂	Percentage of nitrogen by volume, dry.	Dimensionless
% O ₂	Percentage of oxygen by volume, dry.	Dimensionless
$\Delta P_{S,i}$	Velocity pressure of air as determined by Pitot-static tube at point i in the sampling plane.	Pa, (in water)
ΔH_{AVG}	The pressure drop across the orifice of the air flow rate measuring device expressed as the arithmetic average of several readings.	Pa, (in water)
q_i	Angle of deviation between actual direction of airflow at point i in the sampling plane and a normal to the plane.	Degrees
ρ	Density	kg/m ³ , (lb/ft ³)
ρ_d	Average air density at design	kg/m ³ , (lb/ft ³)
ρ_k	Average air density at test	kg/m ³ , (lb/ft ³)
ρ_{cw}	Density of the circulating water	kg/m ³ , (lb/ft ³)

2.0 CONDITIONS OF TEST

2.1 Conduct of Test. Drift acceptance testing shall be conducted by the CTI in the presence of authorized representatives of the tower manufacturer and the tower purchaser, if they elect to attend. For acceptance testing, these representatives shall be given adequate notice to inspect the tower in advance, prepare it for the test and attend testing. In no case shall any directly involved party be barred from the test site.

2.2 Condition of Equipment. At the time of the test, the tower shall be in good operating condition. The Test shall be conducted under the following guidelines:

- Acceptance test(s) shall be conducted within 18 months after structural completion of the tower or 12 months of operation, unless otherwise stipulated by mutual agreement of purchaser and manufacturer. The tower shall have been in operation for sufficient time to satisfy tower manufacturer's published or contractual requirements.

- The water distribution system shall be in good repair and essentially clear and free of foreign materials which may impede the normal water flow.
- Mechanical equipment, if involved, shall be in good working order. Fans shall be rotating in the correct direction, with proper orientation of leading and trailing edges. Axial fan blades shall be at a uniform angle. Centrifugal fans shall be free of foreign material and properly secured to the shafts.
- Drift eliminators shall be essentially clear and free of algae and other deposits which may impede normal air flow.
- Fill shall be essentially free of foreign materials such as oil, tar, scale, or algae which may impede or disrupt normal air or water flow.
- Cross-flow towers should have the cold water basin level at the recommended height to prevent air bypass.

2.3 Operating Conditions. The drift test of any cooling tower shall be conducted within the following limitations:

2.3.1 Requirements for drift testing of any tower shall include:

- The temperature of the inlet air stream should remain above the freezing point of water.
- The sampling area should be free from visible collection of condensation on surfaces.
- The tower should be free of airborne foam at the sampling elevation.
- The test period shall be free from any natural precipitation.

2.3.2 The circulating water flow rate shall be within $\pm 10\%$ of the design value.

2.3.3 The operating fan horsepower of mechanical draft towers, when corrected for air density, shall be within $\pm 10\%$ of the design value.

2.3.4 The wind velocity shall be measured in accordance with Paragraph 3.6 of this test procedure, and shall not exceed the following:

- average wind velocity, ... 4.5 m/s (10 miles per hour)
- one-minute duration 7.0 m/s (15 miles per hour)

2.3.5 At this time there is no documented cause and effect relationship between either wet-bulb temperature or cooling range and drift rate for mechanical draft towers. If contractual drift guarantees are contingent on test measurements being conducted within a range of operating parameters, the operating parameters must be specified in the contract between the tower purchaser and tower manufacturer. Due to the influence of wet-bulb temperature, dry-bulb temperature, and range on airflow for a natural draft tower, the following deviations from design conditions shall not be exceeded:

- Wet-bulb $\pm 8.5^\circ\text{C}$ (15°F)
- Dry-bulb $\pm 14.0^\circ\text{C}$ (25°F)
- Range $\pm 20\%$

2.3.6 For multi-cell towers, one or more cells may be shut down, provided the circulating water flow to each operating cell is within the specified limits. (For the purposes of this Code, a "cell" is defined as the smallest subdivision of the tower, bounded by exterior walls and partition walls, which can function as an independent unit. Each cell may have one or more fans or stacks and one or more distribution systems). The water shall be distributed to all operating cells and/or parts of the tower as recommended by the manufacturer.

2.3.7 For crossflow towers, the water level in the cold water basin shall be maintained at the normal operating level test in order to provide proper air flow to the fill.

2.3.8 General Water Quality

2.3.8.1 The circulating water shall contain not more than 10 mg/l(ppm) oil, tar, or fatty substances as determined by the procedure outlined in "Standard Methods for the Examination of Water, Sewage, and Industrial Wastes", published by the American Public Health Association.

2.3.8.2 Surface active agents (surfactants and/or dispersants) can significantly effect drift eliminator performance and their use should be discontinued beginning three to five days prior to and extending through the drift test.

2.4 Constancy of Test Conditions. For mechanical and natural draft towers, variations in operating conditions over the course of the sampling period shall be within the following limits:

2.4.1 Circulating water flow shall not vary by more than $\pm 5\%$ per hour.

2.4.2 The flow rate of any flow stream entering or leaving the cold water basin (e.g. makeup or blowdown) must remain constant while measurements are being conducted. Side stream filters or reverse osmosis filters must not be activated while drift sampling.

2.4.3 The concentration of the minerals or tracers of each inlet water sample shall not vary more than 10% during each individual test.

2.4.4 To limit significant variations in air flow for a natural draft tower, changes in test conditions shall be within the following limits:

2.4.4.1 Range shall not vary by more than $\pm 5\%$ per hour.

2.4.4.2 Instantaneous air temperature readings may fluctuate, but variations in the averages during the test period shall not exceed the following:

a) Wet-bulb . . . 1°C per hour (2°F)

b) Dry-bulb . . . 3°C per hour (5°F)

2.5 Number of Tests. For acceptance testing, a minimum of two tests with results within $\pm 25\%$ of their average is required on each cell tested. The number and selection of cells tested shall be as contractually or mutually agreed upon. The tests may be conducted simultaneously or sequentially.

2.6 Frequency of Readings. Readings shall be taken at regular intervals and recorded in the units and to the number of significant figures shown in Table 3.

2.7 Test Accuracy. The overall tower drift rate test accuracy depends on the accuracy of chemical analysis and sampling

TABLE 3 Frequency of Readings and Units For Isokinetic Drift Tests

Measurement	Minimum number	Unit	Record to nearest
Exit air velocity or velocity pressure	Every sample point.	m/s, (ft/sec) or Pa, (in H_2O)	0.01 m/s, (0.1 ft/sec) or 2 Pa, (0.01 in.)
Exit air temperature	Every sample point.	$^{\circ}\text{C}$, ($^{\circ}\text{F}$)	0.5, (1.0)
Air Flow angle	Every sample point.	degrees	2
Isokinetic sample rate	Every sample point.	L/s, (ft^3/sec)	0.05, (0.1)
Circulating water reference sample	Beginning, midpoint and end of test.		
Circulating water flow rate	1/hour*	L/s, (gpm)	0.05, (1)
Wind velocity	continuously	m/s, (mph)	0.5, (1)
Barometric Pressure	1/test	kPa, (in. Hg)	0.2, (0.1)
Fan driver power input	1/test**	kw, (hp)	0.05, (0.1)
Wet-bulb temperature	1/hour***	$^{\circ}\text{C}$, ($^{\circ}\text{F}$)	0.05, (0.1)
Dry-bulb temperature	1/hour***	$^{\circ}\text{C}$, ($^{\circ}\text{F}$)	0.05, (0.1)
Cold water temperature	1/hour***	$^{\circ}\text{C}$, ($^{\circ}\text{F}$)	0.05, (0.1)
Hot water temperature	1/hour***	$^{\circ}\text{C}$, ($^{\circ}\text{F}$)	0.05, (0.1)

*If Pitot tube used for water flow measurement, single center point readings for comparison with full traverse reading

** If required (Mechanical Draft Towers)

*** If required (Natural Draft Towers)

techniques, the stability of test conditions, and for multi-cell towers, the number of cells tested and the consistency of construction from cell to cell.

3.0 INSTRUMENTS AND MEASUREMENTS

All air flow, water flow, temperature and power measuring devices shall be inspected and approved by CTI prior to the test. All instruments shall have been calibrated before the test.

3.1 Water Flow Measurements

3.1.1 Water flow measurements may be made by any of the following devices. Any other CTI-approved methods of direct measurement may be used. The selection of method and location of measurement will depend upon the nature of the installation to be tested.

- a) Pitot tube (traverse)
- b) Orifice
- c) Venturi
- d) Magnetic flow meter
- e) Flow nozzle
- f) Turbine meter

3.1.2 The procedure for using any of the above shall be as described in one or more of the following sources:

- a) Instrument manufacturer's instructions
- b) CTI "Acceptance Test Code for Water Cooling Towers", ATC-105 (latest revision)
- c) CTI "Cooling Tower Manual", Chapter 5, Section 5.3 (latest revision)
- d) ASME "Supplements on Instruments and Apparatus," Part 5, Chapter 4 (latest revision)
- e) ASME Power Test Code on "Hydraulic Prime Movers" (latest revision)

3.2 Water Temperature Measurements. At the time of this writing, the effect of heat load on drift from mechanical draft cooling towers has not been fully documented. Reference temperature measurements are recommended for mechanical draft and required for natural draft towers. Measurements should be made with any of the instruments (such as resistance thermometers or mercury-in-glass thermometers) and methods prescribed in ASME "Supplements on Instruments and Apparatus" (latest revision). Instruments shall be graduated in increments of not more than 0.1°C (0.2°F). Temperature-sensitive elements shall be located where the water will be thoroughly mixed.

3.2.1 Hot circulating water temperature measurement shall be made in the tower riser(s) or at the discharge of the inlet riser(s) into the flume or distribution system or, for a multi-cell tower, in the supply header just upstream of the first riser. If the inlet water flow is a mixture of two or more streams of different temperatures, complete mixing must be assured at the point of measurement or sufficient flow rate and temperature measurements shall be made to ensure an accurate weighted average hot water temperature.

3.2.2 Cold circulating water temperature measurements should preferably be made in a full-flowing bleed stream at the circulating pump discharge, and the average cor-

rected for the energy added by the pump(s). If the measurement is made at a location where temperatures and velocities are not uniform over the stream cross-section, sufficient flow rate and temperature measurements shall be made to ensure an accurate weighted average cold water temperature.

3.3 Air Temperature Measurements

3.3.1 Inlet Wet-bulb Temperature. The inlet wet-bulb temperature measurements is recommended for mechanical draft and required for natural draft towers. For measurement of wet-bulb temperatures, a minimum of two instruments on opposite sides of the Tower shall be used to ensure that the test average is within the required limits. Measurements shall be obtained using mechanically aspirated instruments, designed to meet the following requirements:

- a) The indicator or recorder shall be graduated in increments of not more than 0.1°C (0.2°F).
- b) The temperature-sensitive element shall be accurate to $\pm 0.05^\circ\text{C}$ (0.1°F).
- c) The temperature-sensitive element shall be shielded from direct sunlight or from other significant sources of radiant heat. The shielding device shall be within 1°C (2°F) of the surrounding dry-bulb temperature.
- d) The temperature-sensitive element shall be covered with a wick that is continuously fed from a reservoir of distilled water.
- e) The temperature of the distilled water used to wet the wick shall be at approximately the wet-bulb temperature being measured. This may be obtained in practice by providing an adequate length of ventilated wick between the water supply and the temperature-sensitive element.
- f) The wick shall fit snugly over the temperature-sensitive element and extend at least one inch past the element over the stem. It shall be kept clean while in use.
- g) The air velocity over the temperature-sensitive element shall be maintained between 4.5 m/s (950 fpm) and 5.5 m/s (1050 fpm).

3.3.2 Inlet Dry-bulb Temperature. The inlet dry-bulb temperature measurement is required for natural draft towers. For measurement of dry-bulb temperatures, a minimum of two instruments on opposite sides of the tower shall be used to ensure that the test average is within the required limits. Measurements shall be obtained using instruments designed to meet the following requirements:

- a) The indicator or recorder shall be graduated in increments of not more than 0.1°C (0.2°F).
- b) The temperature-sensitive element shall be accurate to $\pm 0.05^\circ\text{C}$ (0.1°F).
- c) The temperature-sensitive element shall be shielded from direct sunlight or from other significant sources of radiant heat. The shielding device shall

be within 1°C (2°F) of the surrounding dry-bulb temperature.

- d) The air velocity over the temperature-sensitive element shall be maintained between 4.5 m/s (950 fpm) and 5.5 m/s (1050 fpm).

3.4 Barometric pressure shall be measured at the sample plane with a meteorological grade barometer accurate to within 0.2 KPa (0.1 In. Hg).

3.5 Sample Point Temperature Measurements. Sample point temperature measurements to determine air properties are required for all types of cooling towers covered in this code. The sample point temperature shall be measured at each station with instruments, meeting the following requirements:

- a) The indicator or recorder shall be graduated in increments of not more than 0.5°C (1.0°F).
- b) The temperature-sensitive element shall be accurate to $\pm 0.5^\circ\text{C}$ (1.0°F).

3.6 Wind Velocity (Speed and Direction). Wind velocity shall be measured with a meteorological type anemometer and wind vane, preferably remote reading and recording. Rotating cup anemometers with separate wind direction vane or combination self-aligning propeller and direction vane devices are readily available and acceptable. Measurements shall be made in an open and unobstructed location, upwind of the tower and beyond the influence of the inlet air approach velocity. Care shall be taken to assure recorded wind speed and direction are representative of wind conditions affecting the tower. Placement of the wind measurement device shall be subject to mutual agreement by all parties to the test. Wind direction shall be recorded in compass degrees with the tower orientation and reference north clearly indicated.

For mechanical draft towers with an overall height of twenty feet or less, wind velocity shall be measured five feet above curb elevation, at a point within 15 to 30 m (50 to 100 feet) of the tower, if practical. For mechanical draft towers where the distance between curb and discharge elevations exceeds 6 m (20 feet), the wind velocity shall be measured at an elevation above the curb elevation which is approximately one-half the difference between the curb and discharge elevations and at a point at least 30 m (100 feet) from the tower, if practical.

3.7 Fan Driver Power. For mechanical-draft and fan-assisted towers, fan power shall be determined as power input to the motor or driver. In the case of electric motors, power input shall be determined by measurement of the voltage, current, and power factor, or by direct measurement of the kilowatt input. If motor input power is not directly measured at the motor, then a line loss correction shall be made, unless otherwise agreed upon by all parties.

3.8 Circulating Water Reference Sample. Samples of the circulating water must be taken from the tower hot water inlet at the beginning, midpoint and end of each individual test. Sample preservation techniques should be implemented according to the requirements provided by the laboratory performing the analysis.

3.9 Drift Measurement Location. Sampling points must be made at the centroid of equal areas in any plane on the discharge side of the drift eliminators where reasonable access can be obtained. Possible measurement locations include the air flow exit plane of the cooling tower, beneath the fans in the stacks, or immediately downstream of the drift eliminators. The measurements are to be taken at a minimum of 24 equal area points in the sample plane.

3.9.1 For circular sample planes without hub effects, including natural draft Towers, the sample locations will be based on the total area and located at the centroids of equal annular sample zones with a minimum of 4 radii and 6 points per radius. If additional locations are desired, the number of radii and/or the number of points per radius may be increased.

3.9.2 For circular sample planes with hub effects, the sample location will be based on the net area and located at the centroids of equal annular sample zones with a minimum of 4 radii and 6 points per radius. If additional locations are desired, the number of radii and/or the number of points per radius may be increased. (For area calculation methods, see CTI Cooling Tower Manual, Chapter 5, Table 15, Alternate Procedure No. 2).

3.9.3 For rectangular sample planes the sample locations will be at the centroids of a matrix of equal area sample zones of similar length and width.

3.10 Drift Collection System.

3.10.1 Sample Point Velocity and Temperature. For isokinetic sampling, both the velocity and temperature measurements must be concurrent with the drift sample collection. For velocity measurements, two types of instruments are commonly used. The potential advantages and limitations of each include:

- a) Air Pitot tube. The air Pitot may be suited for velocity measurements in the cooling tower environment. Total and velocity pressure ports must be large enough in diameter to preclude plugging by water droplets which could cause erroneous results. Air Pitot tubes may be unsuitable for flow measurements at low air velocities due to difficulty of measuring the small differential pressure.
- b) Propeller anemometer. The propeller anemometer may be suitable for velocity measurements in the cooling tower environment. When oriented into the air flow, velocity vectors are easily measured. Potential errors due to rapidly changing vectors are minimized by the cosine response of the instrument. Propeller anemometers are, however, influenced by the impact of water droplets and tend to over measure air flows in pulsing flow regimes such as found over cooling tower fans.

3.10.1.1 Sample plane without angular component. Air velocity and temperature must be measured at each sample location.

3.10.1.2 Sample plane with angular component. Air velocity, temperature and the angle of flow rela-

tive to the sampling plane must be measured at each sample location. Since flow angle can affect the drift results in field tests, the sampling technique must be adjusted to eliminate this bias.

Whenever angular flow is present, the probe must be aligned with the flow to insure isokinetic sampling. If the sample nozzle is oriented normal to the sample plane but not aligned with the airflow, the effective velocity through the nozzle opening is reduced by the cosine of the angle of deviation from normal direction. The sample flow rate will not be isokinetic. If the sample nozzle is aligned with the airflow but not oriented in the normal direction, the sample proportionality for the sample point will be compromised. Isokinetic and proportional sampling needs are both satisfied by orienting the sample probe into the direction of the airflow and adjusting the nominal base sampling time by the cosine of the angular angle of deviation from the normal direction.

When angular measurements are required, a protractor or inclinometer (accurate to 2°) must be mounted on the velocity measuring instrument. The velocity measuring instruments commonly used incorporate one of the following angle indicating devices.

- a) Secondary Pitot tube. A Pitot tube mounted at right angles to the primary velocity measuring device. When the secondary pitot indicates zero or a null manometer reading, the primary pitot is aligned with the air direction.
- b) Directional vane. A sail like device mounted near the primary velocity measuring device on pivots that allow the sail to align itself with the air flow.
- c) Tell-tail. A string or ribbon attached near the primary measuring device to indicate the air flow vector.

3.10.2 Isokinetic Sampling Train. This sampling method collects drift emissions by drawing a portion of the cooling tower exit airstream into a collection apparatus at the same speed and direction (isokinetically) as the local velocity in the cooling tower. The design of the sampler shall be such that external surfaces of the nozzle and above are maintained hot enough to flash off water impinging on the outside surface. Materials of construction in contact with the sample shall not contain any elements or tracers that will be analyzed and shall be appropriate for any rinsing or handling requirements.

3.10.2.1 The primary collection media of the HBIK system consists of a specially configured glass inlet nozzle-tube filled with tightly packed glass beads of approximately 6 mm (1/4 inch) in diameter in a tube of 12 mm (1/2 inch) minimum inside di-

ameter and a minimum of 100 mm (4 inches) long. A heating element and associated temperature control system are used to maintain the sample tube at a temperature sufficient to evaporate the water droplets. The gas temperature leaving the bead pack should be maintained above the boiling point of water at that location, 212°F. The minerals or tracer entrained in the drift water droplets are deposited on the heated glass beads.

3.10.2.2 The secondary collection media of the system is a filter assembly in series with the nozzle-tube. Its purpose is to collect any minerals or tracer which pass through the primary collection media. It is recommended that the filter assembly be attached to or placed as close to the nozzle as practical and oriented to minimize aerodynamic interference with the sample flow. The filter media used should be free of or have very low concentrations of the minerals or tracers to be analyzed. The filter area shall be at least 30 times the glass bead tube cross sectional area, and shall be downstream of an appropriate expansion chamber.

3.10.2.3 A final collection media should be used as a QA/QC indicator to assure collection of the minerals or tracer. The final collection media may consist of additional filters in the above filter assembly or a separate final collection device.

3.10.3 Sample Gas Volume Control and Measurement.

The final collection media outlet is connected via a vacuum tight line to a moisture removal trap which is then connected to a leak free vacuum pump. The vacuum pump has control valves to adjust and maintain the desired sampling rate. The vacuum pump exhaust passes through a console which monitors the sampling process. The console contains a calibrated volumetric or flow rate device with inlet and outlet temperature probes, temperature readout, manometers and associated controls. A dry gas meter is preferred to measure the total volume sampled during the drift test.

3.11 Duration of Test. The duration of the test is governed by the expected drift rate, concentration of minerals or tracers, their relationship to the expected value of procedural blank and the detection limit of the analytical method(s). The test shall be sufficiently long to yield a sample which is a minimum of five (5) times the procedural blank or five (5) times the detection limit of the analytical equipment whichever is greater.

3.12 Inlet Air Background Sample. At the time of this writing the effect of ambient airborne elements entering the tower has not been fully documented. An inlet air background concentration shall be taken concurrently with the drift test. The use of ambient airborne elements as tracers should be avoided in the drift analysis. Types of measurement in common use include suitable ambient air filter samples, or the isokinetic

equipment sampling at an upwind inlet. Analysis is for concentration of elements or tracers present.

3.13 Typical Test Sequence. The typical sequence for a drift test is as follows:

- a) Select sample plane and calculate sample locations.
- b) Assemble drift sampling system and conduct pretest leak check.
- c) Conduct water flow and fan horsepower measurements and initiate monitoring of required test parameters, including background measurement.
- d) Collect circulating water sample.
- e) Initiate isokinetic sampling.
- f) Collect intermediate circulating water sample(s).
- g) Conclude isokinetic drift sampling of the selected sample plane.
- h) Collect final circulating water sample at the conclusion of the test and terminate background sample measurement.
- i) Perform post test leak check on drift sample system.
- j) Recover the drift samples from the sample collection system.
- k) Prepare the drift samples, circulating water samples, water blanks, filter blanks, etc. for transport to the laboratory for analysis.

3.14 Leak Checks. A leak check of the system prior to the start of the sample collection is recommended. If during the sampling run, a component change becomes necessary, a leak check shall be conducted immediately before the change is made. After the component change is completed a leak check of the reassembled system is recommended. A leak check at the conclusion of each test is mandatory before disassembly of the system.

When a dry gas meter is used, pretest leak checks shall be conducted at a 50 kPa (15 in.-Hg) vacuum or the highest vacuum anticipated prior to sampling, whichever is less. Intermediate and post test leak checks shall be at a vacuum equal to or greater than that observed during sampling. If the leakage rate is less than 0.01 l/s (0.02 cfm) or 4% of the average sampling rate, whichever is less, the test results are acceptable without data corrections. If a higher leakage rate is observed, the sample volumes shall either be corrected or the sampling repeated. Equivalent criteria shall be employed with other gas flow measuring systems.

3.15 Sample Recovery. Following the completion of the drift sampling activities, the drift test apparatus should have its external surfaces washed down to remove mineral or tracer deposits. These deposits will bias the laboratory analysis if they were to contaminate the collected samples.

After the external wash down, the sampling apparatus should be moved to a clean area or laboratory for disassembly and recovery of the collected minerals or tracer from the system components.

The sample recovery techniques used should take into consideration the following:

- a) Only ultra pure water and/or reagents should be used to rinse and recover the drift minerals or tracers from the sample apparatus components.
- b) Multiple small volume rinses are preferred to a few large rinses.
- c) The total rinse volume used should be minimized to avoid unnecessary dilution of the samples to be analyzed.
- d) The use of ultrasonic cleaners may enhance sample recovery from the apparatus components, reduce rinse volume and speed recovery.
- e) Filters should only be handled with clean tweezers or tongs.
- f) The recovered materials and rinses should be transferred to pre-cleaned bottles for storage and transfer to the lab for analysis. (Cleaning should be in accordance with recognized protocols for the particular laboratory analysis to be used.)
- g) Samples should be stabilized with appropriate reagents, as recommended, for the laboratory analysis procedure.
- h) Blank or reference samples for the water, reagents and filters used should be prepared at the same time as the sample recovery.
- i) Sample volumes must be accurately measured or weighed to provide data for later calculations.
- j) Samples should be labeled and logged on a custody or transmittal sheet for transfer to a laboratory for analysis.
- k) Gloves or other protective clothing should be worn, as necessary, to protect against contaminating the samples.

3.16 Sample Analysis. Several nationally recognized published reference documents are available for water sample preparation and analysis.

3.16.1 Listed in Appendix A are several preparation methods which are presented for information and references purposes.

3.16.2 Typical Drift Sample Analysis Methods. Quantitative analysis of selected trace elements in both the tower circulating water samples and the collected drift samples are performed by using appropriate analytical instruments. The instrument used must be standardized with one or more standard concentration solutions containing the required reference elements. After the standardization, the detection limit(s) are determined. The final detection limit for each element must account for the magnitude of any interferences from the other elements present in the sample.

Instrument quality control samples should be analyzed to check the instrument operation. If the values are acceptable, the drift test samples are then analyzed. Appropriate corrections to correct for blanks, instrument drift, interferences, sample weight, sample volume, and dilution must be performed as required.

Listed in Appendix B are several analysis methods which are presented for information and references purposes.

4.0 CALCULATIONS

4.1 Calculation of Air Flow

4.1.1 Calculation of Sample Point Velocity. The air velocity at each sampling point is measured by an anemometer or Pitot tube oriented into the flow. To maintain isokinetic conditions, the inlet nozzle velocity of the sampling device is set to match the tower sample plane velocity as closely as possible.

If an anemometer is used, velocity in the flow direction is determined from the anemometer speed (including calibration corrections).

If a Pitot tube is used, velocity in the flow direction is calculated from:

- Air Temperature at the sampling point
- Barometric Pressure
- Static pressure
- Velocity Pressure (Including adjustment for pitot tube coefficient).

4.1.2 Calculation of Sampling Time. If angular flow is present, the angle of the flow direction must be measured in addition to its velocity. The sample time at each point must then be adjusted from the nominal sample time. The adjustment is given by the following equation:

$$t_{2,i} = t_{1,i} * \cos \theta_i \quad (1)$$

For each sample point:

- $t_{2,i}$ = Actual sampling time with adjustment for the angularity of the flow angle, s (sec)
 $t_{1,i}$ = Nominal sampling time, s (sec)
 θ_i = angle between flow direction and the normal to the sample plane, degrees

4.1.3 Calculation of Sample Volume. The isokinetic sample volume is determined for each point from the sample point velocity, nozzle area and adjusted sample time as given in the following equation:

$$V_{S,i} = K * U_{N,i} * A_N * t_{2,i} \quad (2)$$

For each sample point, i:

- $V_{S,i}$ = Sample volume required, L (ft³)
 A_N = Area of nozzle, m² (ft²)
 K = 1000 for SI units (1.0 for I-P units)
 $t_{2,i}$ = Adjusted sample time, s (sec)
 $U_{N,i}$ = Sample velocity at nozzle inlet, m/s (ft/sec)

In most sample collection systems the moisture is removed from the gas stream and the temperature at the sample gas volume control and measurement station differs from the sample temperature. Therefore, the sample volume at the flow measuring device must be corrected as given in the following equation:

$$V_{M,i} = V_{S,i} * \left(\frac{T_{M,i}}{T_{S,i}} \right) * \left(\frac{P_{S,i}}{P_{M,i}} \right) * M_{F,i} \quad (3)$$

For each sample point:

- $V_{M,i}$ = Measured sample volume, L (ft³)
 $V_{S,i}$ = Sample volume required, L (ft³)
 $M_{F,i}$ = Mole fraction of dry gas
 $P_{M,i}$ = Pressure at measuring device, KPa (in. Hg)
 $P_{S,i}$ = Pressure at sample plane, KPa (in. Hg)
 $T_{M,i}$ = Measuring device temperature absolute, °K (°R)
 $T_{S,i}$ = Sample temperature absolute, °K (°R)

If the sample collection system is designed such that no moisture is removed, then $M_{F,i}$ in Equation (3) must be set equal to 1.

4.1.4 Monitoring of Sample Flow. When a dry gas meter is used, the airflow through the sampling system is usually monitored using an orifice or rotameter. These devices are generally located at the dry gas meter outlet. Therefore, the isokinetic meter sample volume may be used to determine the approximate reading required at the orifice or rotameter to initiate the sampling process. The cumulative sample volume should be monitored and adjusted as necessary to maintain isokinetic flow conditions.

4.1.5 Determination of Isokinetic Percentage. When a dry gas meter is used, the test data will be used to calculate the percent of isokinetic conditions achieved during the test. If the test is more than ± 10% from 100% isokinetic the test should be rerun. When an airflow meter is used, such as rotameter, 100% isokinetic must be assumed.

4.2 Calculation of Drift Emission Rate. If several tracers are sufficiently concentrated for analysis, the results are presented in tabular format for comparison. The following equation is used to calculate the drift results:

$$\% \text{ Drift} = K_1 * \frac{A_{SP}}{A_N} * \frac{W_T}{Q_{WT} * t_E * C_{TC} * \rho_{CW}} \quad (4)$$

Where:

- A_N = Nozzle area, m² (ft²)
 A_{SP} = Sample plane area, m² (ft²)
 C_{TC} = Circulating Water tracer concentration, Mg/L (ppm)
 K_1 = 100,000 for SI units (98,861 for I-P units)
 Q_{WT} = Water flow rate during test, L/s (gpm)
 ρ_{CW} = Density of water, kg/m³ (lb/ft³)
 t_E = Total equivalent sample time, s (sec)
 W_T = Net weight of tracer, mg

5.0 REPORT OF RESULTS

5.1 Scope. The report of the test shall include:

- Calculated drift rate.
- The data required by this test procedure.
- Any deviations from this procedure.
- A description of the cooling tower with its orientation and principle dimensions.