

# COOLING TECHNOLOGY INSTITUTE

## Acceptance Test Procedure for Wet-Dry Plume Abatement Cooling Towers



July 2011

# FOREWORD

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

Approved by the CTI Executive Board.



This document has been reviewed and approved as part of CTI's Five Year Review Cycle. This document is again subject to review in 2016.

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ATC-150 (11)

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## Part I – Test Procedure

### 1.0 SCOPE AND PURPOSE

**1.1 Scope.** This code covers the determination of the effluent air or plume characteristics of wet-dry cooling towers, designed for plume abatement.

**1.2 Purpose.** The purpose of this code is to describe instrumentation and procedures for the testing and performance evaluation of the plume characteristics of wet-dry cooling towers.

**1.3 Flexibility.** It is recognized that the data limitations specified throughout this test procedure represent desired conditions that may not exist at the time the test is performed. In such cases, existing conditions may be used if mutually agreed upon by authorized representatives of the manufacturer, the purchaser, and the CTI Representative (see 1.4), prior to the test.

**1.4 Impartial Testing Service.** It is the intention of the Cooling Technology Institute to provide independent third-party thermal performance tests. This means that any situation in which the testing agency has a material or any other interest in the outcome of the test must be avoided.

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 Technology Institute, but must have a license agreement with the latter. This Representative shall be sufficiently qualified to ensure that measurements and evaluations are made in accordance with this Code. The CTI Representative is hereinafter referred to as the CTI-licensed Test Agency.

1.4.1 Certain categories of business interests or activities may compromise the objectivity of an agency and are considered by CTI as inappropriate for an organization licensed to provide impartial testing services. When any portion of the revenues of a testing agency or any of its

corporate parents or subsidiaries is derived from these interests or activities this will preclude that organization from consideration. The following is a non-exclusive listing of examples of these categories of business interests or activities:

- a) The manufacture, repair, replacement, or upgrade of cooling towers or cooling tower components.
- b) Operation or ownership of cooling towers related to primary income generating processes.

1.4.2 Further, any specific situation in which the testing agency can be said to have an interest in the outcome of a particular test is considered a conflict of interest and is to be avoided. The following is a non-exclusive listing of examples of such situations:

- a) Performing cooling tower design, engineering, construction, or related consultation services, such as bid evaluation, for a party to a particular test (for the purposes of this Section, operation and maintenance recommendations do not constitute related consultation services ).
- b) Engaging in a contractual or business relationship with the cooling tower manufacturer, constructor, or supplier of components or equipment on a particular tower to be tested. (A conflict of interest shall not exist if the testing agency has conducted independent testing of other cooling towers for cooling tower owners, manufacturers, constructors, or suppliers of components and equipment.)

**1.5 Nomenclature.** The symbols used in this Code are identified in the following tabulation. The Code refers to SI unit as primary system and I-P unit as secondary system.

| Symbol          | Description                                  | SI Unit     | I-P unit    |
|-----------------|----------------------------------------------|-------------|-------------|
| $A_m$           | Area associated with traverse point m        | $m^2$       | $ft^2$      |
| $D_f$           | Fan stack exhaust diameter                   | m           | ft          |
| $D_h$           | Fan hub diameter                             | m           | ft          |
| $\Delta D_{rh}$ | Difference of Maximum Relative Humidity      | %           | %           |
| $M_Q$           | Mixing quality coefficient                   | %           | %           |
| M               | Number of sampling points on a single radius |             |             |
| m               | Sampling point (sequence) number             |             |             |
| $P_B$           | Barometric pressure (psychrometric)          | kPa         | "Hg         |
| $P_{Bm}$        | Barometric pressure measured at test         | kPa         | "Hg         |
| $Q_w$           | Circulating Volume water flow                | l/s         | GPM         |
| $Q_{wbd}$       | Blow-down water flow                         | l/s         | GPM         |
| $Q_{wmu}$       | Make-up water flow                           | l/s         | GPM         |
| R               | Cooling Range                                | $^{\circ}K$ | $^{\circ}F$ |
| $Rh_u$          | Up-wind air relative humidity                | %           | %           |

|                                                                              |                                                     |                   |                    |
|------------------------------------------------------------------------------|-----------------------------------------------------|-------------------|--------------------|
| $Rh_e$                                                                       | Exhaust air relative humidity                       | %                 | %                  |
| $Rh_i$                                                                       | Inlet air relative humidity                         | %                 | %                  |
| $T_{CW}$                                                                     | Cold water temperature                              | °C                | °F                 |
| $T_{DBu}$                                                                    | Air up-wind dry bulb temperature                    | °C                | °F                 |
| $T_{DBe}$                                                                    | Exhaust air dry bulb temperature                    | °C                | °F                 |
| $T_{DBi}$                                                                    | Air inlet dry bulb temperature                      | °C                | °F                 |
| $T_{bd}$                                                                     | Blow-down temperature                               | °C                | °F                 |
| $T_{mu}$                                                                     | Make-up temperature                                 | °C                | °F                 |
| $T_{HW}$                                                                     | Hot water temperature                               | °C                | °F                 |
| $T_{WBU}$                                                                    | Up-wind air wet bulb temperature                    | °C                | °F                 |
| $T_{WBe}$                                                                    | Exhaust air wet bulb temperature                    | °C                | °F                 |
| $T_{WBi}$                                                                    | Inlet air wet bulb temperature                      | °C                | °F                 |
| $v_m$                                                                        | Local air velocity at exhaust area traverse point m | m/s               | fpm                |
| $v_v$                                                                        | Vertical component of $v_m$                         | m/s               | fpm                |
| $v_{vi}$                                                                     | Marked local air velocity $v_v$ at exhaust area     | m/s               | fpm                |
| $W1..W5; X1..X5; Y1..Y5; Z1..Z5$                                             |                                                     |                   |                    |
| Names of the measurements points above the fan stack at the radii W, X, Y, Z |                                                     |                   |                    |
| $\alpha$                                                                     | Angle of exhaust air velocity (from vertical)       | deg               | deg                |
| $\rho_m$                                                                     | Density of air at traverse point m                  | kg/m <sup>3</sup> | lb/ft <sup>3</sup> |

## 1.6 Definitions:

1.6.1 Wet section: The wet section of the cooling tower is the evaporative heat transfer media.

1.6.2 Dry section: The dry section of the cooling tower is the non-evaporative heat transfer media.

1.6.3 Cooling tower cell: A cooling tower "cell" is 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 system.

## 1.7 Selection of the design point for the plume abatement condition

1.7.1 The visibility of the plume is given by the condensation droplets generated when the warm and saturated exhaust air of the cooling tower is in contact with colder air inside or outside of the cooling tower. The exhaust air temperature and humidity are directly related to the inlet air temperature and humidity and the operating conditions of the cooling tower (Range and flow), and may be described as a function of dry bulb and relative humidity or wet bulb conditions as guaranteed effluent air performance curves that must go through the selected design point.

1.7.2 For a given operating condition, a curve exists relating the inlet air temperature and the inlet humidity, and separating the visible plume from the non-visible plume conditions (Graph having relative humidity on the ordinate and the air dry bulb temperature on the abscissa or Psychrometric chart). This curve is called the "Fogging frequency curve". On the same graph or chart, the site weather statistics can be plotted (all temperature / humidity

points during the year or only those corresponding to the daylight points); any site weather conditions "above" (more severe than) the fogging frequency curve will generate visible plume; any site weather conditions "below" (less severe than) the fogging frequency curve will not generate visible plume. It is possible then to calculate the percentage of total hours per year (or daylight hours per year) for which some visible plume may occur. This percentage is an estimate of the occurrence of visible plume.

1.7.3 The selection of the plume abatement design point depends mainly on the location of the cooling tower and the local requirements. It drastically affects the cost of the wet-dry cooling tower. If no plume may occur during the year, the coldest temperature / highest humidity point must be selected. Such a severe plume abatement requirement is seldom the case. Severe conditions correspond to 5% or less plume visibility occurrence. A more typical design point corresponds to 15% to 20% plume visibility occurrence based on full year day-night weather statistics. Any point (temperature / humidity) located on the fogging frequency curve gives the same cooling tower design and the same plume visibility occurrence. It is recommended that a winter design point be selected, on such a curve, which is above the freezing point to be able to test the cooling tower, following this code, at conditions close as possible to the design point. The plume abatement design point includes the maximum anticipated heat load coincident with the desired design dry

bulb along with the highest relative humidity at that dry bulb. An example of design point selection and fogging frequency curves with weather statistics is given in appendix A.

1.7.4 In the case where a plume design point requires use of partial damper closure, an alternate design point shall be selected with dampers open. The imprecision of damper settings with regard to establishing that required operating configuration is in effect at the time of testing makes this a necessity. Effluent air curves shall be drawn for the dampers open design point, for evaluation of the test results.

1.7.5 For a given design point, there are two levels of plume abatement that a tower can be guaranteed and tested for in accordance with this test procedure. The definition of Level 1 or Level 2 plume abatement has an effect on the design of the wet-dry cooling tower and on the criteria described in this code to fulfill the plume performance guarantee.

1.7.5.1 Level 1 Plume Guarantee. In order for a tower to meet Level 1 criteria, the ratio (expressed as a percentage) between the guarantee and measured exhaust air relative humidity must exceed 100%, as described in Sections 5 and 6. Level 1 is less stringent than Level 2 and the impact of specifying a Level 1 guarantee could be a translucent plume visible at the exhaust extending up to 2 fan diameters, even under conditions equal to or less severe than the plume abatement design point. Where the Level 1 visible plume guarantee is acceptable, the cost and penalty in pressure drop and required fan power associated with internal plenum mixing devices may be avoided to an extent that is the manufacturer's responsibility to determine.

1.7.5.2 Level 2 Plume Guarantee. Level 2 is the more stringent requirement and in addition to meeting Level 1 exhaust air relative humidity ratio requirements, an exhaust air mixing criteria must also be met, as described in Sections 5 and 6. The intention of the mixing criteria is to ensure that the potential for plume visibility is minimized as much as possible, greatly decreasing the chances for the translucent plume that may occur in Level 1 designed towers.

1.7.4.3 There exists a phenomenon where plume reformation can occur. Plume that is not visible immediately above the fan stacks becomes visible some distance away from the cooling tower when the water vapor in the air condenses due to specific or localized atmospheric conditions and site topography. Conditions that will cause this phenomenon are unpredictable but typically infrequent and plume reformation can occur with both Level 1 and Level 2 designed towers. The plume abatement guarantee is applicable ONLY to the conditions at the air exhaust.

1.7.6 The design air temperature and humidity is defined as the entering air at the up-wind cooling tower air inlets, assuming isothermal atmosphere. (This may be different from the ambient air temperature and humidity)

## 2.0 CONDITIONS OF TEST

**2.1 Conduct of Test.** The test shall be conducted by a CTI-licensed Test Agency, in the presence of authorized representatives of the manufacturer and the purchaser if they desire to be present. For acceptance testing, these representatives shall be given adequate notice prior to the test. The manufacturer shall be given permission to inspect the tower in advance to determine if any preparations to the tower are required prior to the test. In no case shall any directly involved party be barred from test site. Acceptance test(s) shall be conducted within 12 months after structural completion of the tower, unless otherwise stipulated by contractual agreement of purchaser and manufacturer.

If the plume abatement guarantee is related to a "winter mode" thermal performance guarantee by the purchase contract, the plume abatement test and a thermal performance test in winter condition mode (following CTI ATC-105) shall be conducted concurrently.

**2.2 Selection of the tested cell(s)** As the parameters associated with a plume performance test are time consuming and difficult to measure, the test shall be performed on one cell only, which is selected to represent the whole cooling tower. If no single cell may represent the whole cooling tower, the test may be conducted on several cells. In such case, the final performance result will be the weighted average of the individual performance results by the number of cells having the same design as cells tested. Representatives of all the parties of the test shall agree prior to test which cell or cells shall be tested for the plume performance test. All the measurements described in this code, (in particular the air temperatures and velocities), will concern the selected cell(s). If the individual water temperatures and flows cannot be measured, the ones of the whole cooling tower will be taken into consideration.

Note: In the case when a thermal performance test is conducted concurrently, other measurements shall be taken to comply with the CTI ATC-105 test code.

**2.3 Condition of Equipment.** At the time of the test the tower shall be in good operating condition:

- a. The water distribution system shall be essentially clear and free of foreign materials that may impede the normal water flow.
- b. Mechanical equipment shall be in good working order. Fans shall be rotating in the correct direction, with proper orientation of leading and trailing edges. Fan blades shall be at a uniform angle that will yield within  $\pm 10$  percent of the guaranteed fan driver power.
- c. Drift eliminators shall be essentially clear and free of algae and other deposits that may impede normal air flow.
- d. Fill material shall be essentially free of foreign materials such as oil, tar, scale, fouling or algae.
- e. The water level in the cold water basin shall be at normal operating elevation and shall be maintained substantially

constant during the test.

f. Dry sections shall be essentially free of foreign materials, both inside and outside.

g. In freezing weather, the dry sections and the wet sections shall be free of ice formation that may affect the performance of the cooling tower.

h. If applicable, air and water flow control devices shall be set according to the manufacturers recommendations to achieve both the required plume abatement and thermal performance.

Representatives of purchaser and manufacturer shall agree to the operability and functionality of the cooling tower equipment prior to testing. Prior establishment of cleanliness and serviceability is recommended.

**2.4 Operating conditions.** The test shall be conducted within the following limitations:

2.4.1 For the plume evaluation, both the inlet and up-wind wet-bulb and dry-bulb temperatures shall be measured in accordance with Section 3.3 and 3.4 of this test procedure. The inlet air temperatures will be used for evaluating the expected exhaust air conditions from performance curves, and the up-wind air temperatures will be used in the dilution calculation of the plume in the atmosphere (which is assumed as isothermal). If a thermal evaluation is required, the wet-bulb for thermal test calculations shall be the inlet values as described in CTI ATC-105.

2.4.2 The wind velocity shall be measured in accordance with Section 3.7 of this test procedure, and shall not exceed the following:

a) average wind velocity : 3 m/s (6.5 MPH)

b) one-minute duration : 4.5 m/s (10 MPH)

The reliability of the exhaust air measurements increases when the wind velocity decreases. The lowest possible wind speed conditions shall be sought for testing.

2.4.3 To get reliable air inlet and up-wind measurement the minimum wet bulb when measured with a CTI mechanically aspirated psychrometer is 0.5 °C (33 °F). The CTI psychrometer shall be as defined in CTI ATC-105 sections relating to Inlet Air Temperature Measurements. For any design conditions below freezing, the test has to be performed between 0 °C (32 °F) and 8 °C (45 °F) up-wind wet bulb temperature.

2.4.4 The following variations from design conditions shall not be exceeded:

2.4.4.1 Wet-bulb temperature: -0.0 °C / + 8.5 °C (15 °F)

2.4.4.2 Dry-bulb temperature: -0.0 °C / + 14.0 °C (25 °F)

2.4.4.3 Cooling range: ± 20 %

2.4.4.4 Circulating water flow: ± 10 %

2.4.4.5 Barometric pressure: ± 3.5 kPa (1" Hg)

2.4.4.6 Heat load of dry section: ± 10 % (See note 1)

2.4.4.7 Water flow in dry section: ± 10% (See note 1)

2.4.4.8 Fan(s) drivers power: ± 10%

Note 1: Applicable only on wet/dry towers having separate heat load supply on the wet and the dry sections.

2.4.5. For a multi-cell tower each of the tested cells must be set within ± 5% of average operating conditions of all the cells: the water flow rates, fan driver power, air flow control devices position (if applicable) and heat load on the dry section (if applicable).

2.4.6 For multi-cell towers, one or more cells may be shut down, provided that the circulating water flow to each operating cell is within the above limits.

2.4.7 The total dissolved solids in the circulating water, as determined by evaporation, shall not exceed the greater of the following:

a) 5000 ppm

b) ± 10% of the design concentration

The circulating water shall contain not more than 10 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.

The limit for foreign substances in the circulating water shall be by prior mutual agreement by the purchaser and the manufacturer.

**2.5 Duration of test.** After reaching steady state conditions, the duration of one test run shall not be less than one hour. (Exhaust air wet and dry bulb temperature, exhaust air velocity.) (This shall be called the Test Period)

2.5.1 If thermal lag time is greater than five minutes, the test period shall be extended by the actual thermal lag time. (Calculated as in CTI ATC-105)

2.5.2 The test period for thermal evaluation shall have the same duration as the plume characteristics evaluation.

**2.6 Constancy of test conditions during test period.** For a valid test, variations from maximum to minimum of 1 minute averages in test conditions shall be within the following limits:

2.6.1 Circulating water flow shall not vary more than 2 %.

2.6.2 Heat load shall not vary by more than 5 %.

2.6.3 Range shall not vary by more than 5 %.

2.6.4 Instantaneous up-wind and inlet air temperature readings may fluctuate during the test, but the linear least squares trend in the reading average for all stations for the test period shall not exceed the following limits:

1) Up-wind and Inlet air dry-bulb temperature  
3 °C/period (5 °F/period)

2) Up-wind and Inlet air wet bulb temperature  
1 °C/period (2 °F/period)

2.6.5 Heat load and water flow rate of the dry section shall not vary by more than 5%. (Applicable only on towers having separate heat load supply on the wet and the dry sections.)

**2.7 Frequency of readings.** Readings shall be taken at regular intervals and recorded in the units and to the number of significant figures shown in the table in Section 2.9.

2.7.1 The readings may be recorded manually and/or with a data acquisition system (DAS). Both methods may be utilized during the same test.

2.7.2 Not all measurements given in the Instrumentation Table in 2.9 are always used for wet/dry cooling towers. The necessary measurements for the plume characteristic evaluation depend on the wet/dry cooling tower type and shall be determined by prior mutual agreement with the purchaser, the manufacturer, and the CTI representative.

## 2.8 Test uncertainty.

2.8.1 Instrumentation accuracy. The accuracy of each measurement device shall be equal to or better than those indicated in the table in Section 2.9. Other instrumentation may be used by prior mutual agreement with the purchaser, the manufacturer, and the CTI representative.

2.8.2 Overall uncertainty. The overall test uncertainty depends on the type and number of instruments used for the various measurements, and on the stability of test conditions.

## 2.9 Instrumentation Table

| Measurements                              | Minimum/hr |     | SI units |     |      | I-P units |     |      |
|-------------------------------------------|------------|-----|----------|-----|------|-----------|-----|------|
|                                           | Man        | DAS | #        | Acc | Rec  | #         | Acc | Rec  |
| Inlet air wet-bulb temp                   | NA         | 60  | °C       | 0.1 | 0.05 | °F        | 0.2 | 0.1  |
| Inlet air dry-bulb temp                   | NA         | 60  | °C       | 0.1 | 0.05 | °F        | 0.2 | 0.1  |
| Up-wind air wet-bulb temp                 | NA         | 60  | °C       | 0.1 | 0.05 | °F        | 0.2 | 0.1  |
| Up-wind air dry-bulb temp                 | NA         | 60  | °C       | 0.1 | 0.05 | °F        | 0.2 | 0.1  |
| Exhaust air wet-bulb temp <sup>1</sup>    | NA         | 60  | °C       | 0.1 | 0.05 | °F        | 0.2 | 0.1  |
| Exhaust air dry-bulb temp <sup>1</sup>    | NA         | 60  | °C       | 0.1 | 0.05 | °F        | 0.2 | 0.1  |
| Cold water temp (wet)                     | NA         | 60  | °C       | 0.1 | 0.05 | °F        | 0.2 | 0.1  |
| Cold water temp (dry) <sup>3</sup>        | NA         | 60  | °C       | 0.1 | 0.05 | °F        | 0.2 | 0.1  |
| Hot water temp (wet)                      | NA         | 60  | °C       | 0.1 | 0.05 | °F        | 0.2 | 0.1  |
| Hot water temp (dry) <sup>3</sup>         | NA         | 60  | °C       | 0.1 | 0.05 | °F        | 0.2 | 0.1  |
| Circulating water flow (wet) <sup>2</sup> | 3          | 60  | l/s      | 3%  | 0.5% | gpm       | 3%  | 0.5% |
| Circulating water flow (dry) <sup>2</sup> | 3          | 60  | l/s      | 3%  | 0.5% | gpm       | 3%  | 0.5% |
| Fan driver power (wet)                    | 1/test     |     | kW       | 3%  | 0.5% | HP        | 3%  | 0.5% |
| Fan driver power (dry) <sup>3</sup>       | 1/test     |     | kW       | 3%  | 0.5% | HP        | 3%  | 0.5% |
| Exhaust air velocity <sup>1</sup>         | NA         | 60  | m/s      | 0.1 | 0.05 | fpm       | 20  | 10   |
| Wind velocity                             | NA         | 60  | m/s      | 0.1 | 0.05 | mph       | 0.2 | 0.1  |
| Barometric pressure                       | 1/test     | 60  | kPa      | 0.2 | 0.1  | “Hg       | .06 | .03  |
| Make-up water temperature                 | 2          | 2   | °C       | 0.1 | 0.05 | °F        | 0.2 | 0.1  |
| Make-up water flow rate <sup>4</sup>      | 2          | 60  | l/s      | 5%  | 1%   | gpm       | 5%  | 1%   |
| Blow-down water temp                      | 2          | 2   | °C       | 0.1 | 0.05 | °F        | 0.2 | 0.1  |
| Blow-down water flow rate <sup>4</sup>    | 2          | 60  | l/s      | 5%  | 1%   | gpm       | 5%  | 1%   |

“Minimum” = Minimum number of records each hour per station

“Man” = Manual measurements

“DAS” = Measurements with Data Acquisition system

“Acc” = Sensor accuracy

“Rec” = Recording to the nearest

<sup>1</sup> A total of 20 simultaneous point measurements are made and scanned with remote data acquisition equipment. Instruments are deployed at equal area stations along two perpendicular diameters.

<sup>2</sup> To monitor circulating water flow stability, the differential pressure at a single point can be monitored during the test for comparison with full traverse readings (when measurement is made by Pitot tube), alternately for the entire tower, the exhaust pressure of the circulating water pumps can be used as an indication of flow stability.

<sup>3</sup> If applicable or required for towers with separate wet and dry fans, or special flow bias

<sup>4</sup> Or totalized values per test

### 3.0 INSTRUMENTS AND MEASUREMENTS

All instruments used shall be inspected and approved by the CTI-licensed Testing Agency prior to the test. All instruments shall be properly calibrated and meet the accuracy requirements of Table 2.9. Calibration certificates shall be made available to test parties upon request.

**3.1 Waterflow measurements.** The total water flow delivered to both the dry and wet sections of the cooling tower must be measured, unless all of the water flows in series from the dry section to the wet section. If all of the water flows from the dry to the wet section, only the flow delivered to the dry section is required. The waterflow must be determined with a device meeting the requirements of CTI ATC-105.

#### 3.2 Water temperature measurements.

**3.2.1 Hot water temperature -** The hot water temperature delivered to both the dry and wet sections of the test cell must be measured unless all of the water flows in series from the dry section to the wet section. If all of the water flows from the dry to the wet section, only the temperature of the water delivered to the dry section is required. The hot water temperature must be measured with a device that is compliant with requirements of CTI ATC-105.

**3.2.2 Cold water Temperature** The cold water temperature is defined as the average temperature of the water as it reaches the cold water basin of the cell that is under test. The cold water temperature is often measured on the exhaust side of the operating pump(s), with corrections made for the heat added by the pumps and for the effluent air of the cooling tower. The measurements shall be made at the exhaust plane of the fan stack of an induced draft cooling tower cell or the exhaust plane area of a forced draft cooling tower.

**3.5.1 Exhaust wet-bulb temperature.** The exhaust wet-bulb temperature shall be measured with a twenty point array of mechanically aspirated psychrometers. Each instrument shall meet the same requirements as the inlet wet bulb temperature measurement described in CTI ATC-105.

**3.5.2 Exhaust dry-bulb temperature.** The exhaust dry-bulb temperature shall be measured with a twenty point array of mechanically aspirated psychrometers. Each instrument shall meet the same requirements as for the inlet dry bulb temperature measurements as described in CTI ATC-105. The psychrometers shall be designed to prevent any water droplets from impinging on the sensing element.

**3.5.3 Location of the measurements:** In order to avoid wind effects, the measurements shall be taken at the centers of equal areas of the fan stack in a plane within 1 meter (3 ft) of the cooling tower exhaust plane. The exhaust air velocity measurements (as described in 3.6) shall be taken simultaneously with the wet-bulb and dry-bulb exhaust measurements. The airflow measurement devices shall be made as close as possible to the equal area station where the exhaust wet-bulb and dry-bulb temperatures are measured.

For small stacks the number of measurement points may

influence of any entering or exiting flows, including makeup or blow down. If more than one cell of a plume abated tower is in service at the time of a single cell plume abatement test, the water flow rate of the test cell must be within five percent of the average cell flow rate, and all cells receiving water must be operated at the same fan speed. If fan power in each cell is being measured (as for a concurrent thermal test) the fan power for the test cell should be within 10% of the average fan power. The cold water temperature must be measured with a device that is compliant with requirements of CTI ATC-105.

**3.3 Inlet air temperature measurements.** Air inlet wet-bulb and dry-bulb temperatures are required at both the wet section and dry section air inlets. The number and location of instruments shall be as required in CTI ATC-105.

**3.4 Up-wind air-temperature measurements.** The up-wind wet-bulb and dry-bulb temperatures are the air inlet values from measurements located on the up-wind face of the cooling tower row. Where an installation has multiple towers, each individual line of tower cells is called a "row" for this purpose.

**3.4.1** If there are other heat sources in the vicinity of the test cell, psychrometers measuring the wet and dry bulb temperature should be located in an area uninfluenced by either the cooling tower or other heat sources in order to measure the upwind ambient conditions.

**3.5 Exhaust air temperature measurements** Simultaneous measurement of the exhaust air wet-bulb and dry-bulb temperatures are required to determine the characteristics of the

be reduced, by mutual agreement between the parties, with a minimum of eight sampling stations at the fan stack or cooling tower exhaust exit plane.

**3.5.3.1** For circular sample planes without hub effects, the samples locations will be based on the total area and located at the centers of equal annular sample zones with 4 radii and 5 points per radius.

For circular sampling planes the position of the sampling locations is calculated by:

$$X_m = \frac{D_f}{2} - \sqrt{\left[\left(\frac{2M - 2m + 1}{8M}\right)(D_f^2 - D_h^2)\right] + \left(\frac{D_h}{2}\right)^2}$$

where

$X_m$  = sample location, distance from wall

$D_f$  = stack diameter

$D_h$  = hub diameter

$M$  = number of sampling points on a single radius

$m$  = sampling point number

The hub diameter should be the larger of diameter of the fan hub seal disk or the diameter of the circle described by the base of the fan blades. This equation may also be used to calculate the sample positions for circular sample planes without hub effects by setting the hub diameter equal to zero.

**3.5.3.2** For circular sample planes with hub effects, the