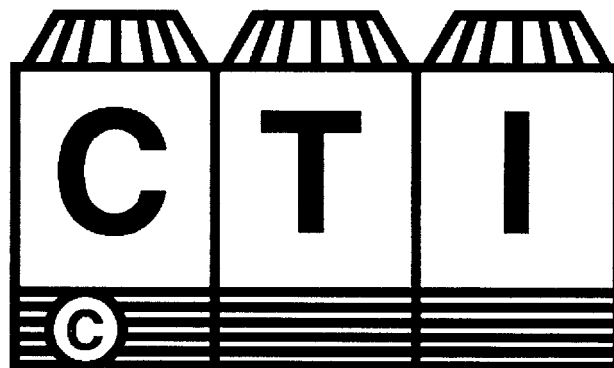


COOLING TOWER INSTITUTE

CTI CODE TOWER Standard Specifications

Acceptance Test Procedure for Wet-Dry Plume Abatement Cooling Towers



April 1999

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FOREWORD

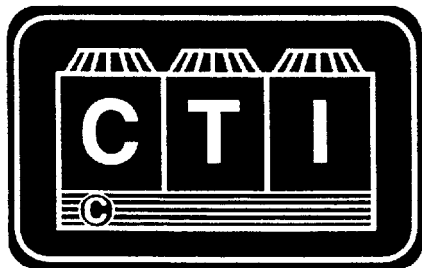
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This guideline document summarizes the best current state of knowledge regarding the specific subject. This document represents a consensus of those individual members who have reviewed this document, its scope and provisions. It is intended to aid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

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 2004.

Approved by the
CTI Executive Board

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Acceptance Test for Wet-Dry Plume Abatement Cooling Towers

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PART I

Test Procedure

1. 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 which 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, prior to the test.

1.4 Impartial Testing Service. It is the intention of the Cooling Tower 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-licensed Test Agency 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 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 paragraph, 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
D_f	Fan stack exhaust diameter	m	ft
DD_{rh}	Difference of Maximum Relative Humidity	%	%
M_Q	Mixing quality coefficient	%	%
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

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Symbol	Description	SI Unit	I-P Unit
R	Cooling Range	°K	°F
Rh	Up-wind air relative humidity	%	%
Rh _u	Exhaust air relative humidity	%	%
Rh _e	Inlet air relative humidity	%	%
T _i	Cold water temperature	°C	°F
T _{CW}	Air up-wind dry bulb temperature	°C	°F
T _{DBu}	Exhaust air dry bulb temperature	°C	°F
T _{DBe}	Air inlet dry bulb temperature	°C	°F
T _{DBi}	Blow-down temperature	°C	°F
T _{bd}	Make-up temperature	°C	°F
T _{mu}	Hot water temperature	°C	°F
T _{HW}	Up-wind air wet bulb temperature	°C	°F
T _{WBU}	Exhaust air wet bulb temperature	°C	°F
T _{WBe}	Inlet air wet bulb temperature	°C	°F
T _{WBi}	Measured local air velocity at exhaust area	m/s	fpm
v _m	Vertical component of v	m/s	fpm
v _v	Marked local air velocity v _m at exhaust area	m/s	fpm
v _{vi}			
W1..W5; X1..X5; Y1..Y5; Z1..Z5	Names of the measurements points above the fan stack at the radii W, X, Y, Z		
a	Angle of discharge air velocity	deg	deg

1.6 Definitions:

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

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

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 "non visible plume" 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 is directly related to the inlet air temperature and humidity and the operating conditions of the cooling tower (range and flow).

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 temperature on the abscissa or psychrometric chart). This curve is called the "Fog-

ging 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 the plume visibility occurrence.

1.7.3 The selection of the "non visible plume" design point depends mainly on the location of the cooling tower and the local requirements. It affects drastically the cost of the wet-dry cooling tower. If no plume may occurs 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 a 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 to the design point.

An example of design point selection and fogging frequency curves with weather statistic is given in appendix A.

1.7.4 Cooling towers are often located in factories with taller installations around them. It can then be acceptable to have light visible plume located above the fan exhaust area, extending around 15m - 50ft. In such a case, the design of the wet-dry cooling tower is called "Limited visible plume." In case such light visible plume is not acceptable, meaning that, at the design point, no visible plume may occur, even just above the fan stack area, the design of the wet-dry cooling tower is called "Zero visible plume."

1.7.5 The definition of "**Limited or Zero visible plume**" 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.

1.7.6 Remarks:

1.7.6.1 The fogging frequency curve cuts across the weather data at a sloped curve on a psychrometric chart. Counting hours at a particular air temperature will induce an over estimate plume visibility occurrence.

1.7.6.2 The design air temperature and humidity is defined as the entering air up-wind from the cooling tower row, assuming isotherm atmosphere. (It may be different from the ambient air temperature and humidity.)

1.7.6.3 It is recommended that a "winter mode" thermal performance design point be associated with the plume design point.

2. Conditions of Test

2.1 Conduct of Test. The test shall be conducted by the 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 measurement of the associated with a plume performance test are time

consuming and difficult, the test will be performed on one cell only representing 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.

Remark: In case of thermal performance test is conducted concurrently, other measurements will be taken to comply with CTI ATC-105 code.

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

- The water distribution system shall be essentially clear and free of foreign materials which may impede the normal water flow.
- 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 ± 10 percent of the specified fan driver power.
- Drift eliminators shall be essentially clear and free of algae and other deposits which may impede normal air flow.
- Fill material shall be essentially free of foreign materials such as oil, tar, scale, fouling or algae.
- Water level in the cold water basin shall be at normal operating elevation and shall be maintained substantially constant during the test in order to provide proper air flow to the fill.
- Dry sections shall be essentially free of foreign materials, both inside and outside.
- In freezing weather, the dry sections and the wet sections shall be free of ice formation which may affect the performance of the cooling tower.
- If applicable, air and water flow control devices shall be set according to the manufacturers recommendations to achieve 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 paragraph 3.3 and 3.4 of this

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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 (assumed as isotherm).

If a thermal evaluation is required, the wet-bulb shall be the inlet values as described in CTI ATC-105.

2.4.2 The wind velocity shall be measured in accordance with paragraph 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 fan effluent measurements increases when the wind velocity decreases. The lowest possible wind speed conditions shall be sought for testing.

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

2.4.3.1 To get reliable air inlet and up-wind measurement the minimum wet bulb when measured with a CTI mechanically aspirated psychrometer is 0°C (32°F).

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

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

2.4.3.4 Cooling range: $\pm 20\%$

2.4.3.5 Circulating water flow: $\pm 10\%$

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

2.4.3.7 Heat load of dry section: $\pm 10\%$ (See note 1)

2.4.3.8 Water flow in dry section: $\pm 10\%$ (See note 1)

2.4.3.9 Fan(s) drivers power: $\pm 10\%$

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.

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.

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

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

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

a) 5 000 ppm

b) $\pm 10\%$ 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 or less than the time used to complete the fan effluent measurement. (Exhaust air wet and dry bulb temperature, exhaust air velocity.) (This shall be called the **Test Period**.)

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

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

2.6 Constancy of test conditions during test period. For a valid test, variations 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, but variations in the average during the test period shall not exceed the followings :

1) Up-wind and Inlet air dry-bulb temperature 3°C/period (4.5°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 following tabulation. (Paragraph 2.9)

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

- Not all measurements given in the following tabulation are always used for wet/dry cooling towers. The necessary measurements for the thermal evaluation and the plume characteristic evaluation depend on the wet/dry cooling tower type and shall be determined by prior