

COOLING TECHNOLOGY INSTITUTE

ACCEPTANCE TEST CODE *for* MECHANICAL DRAFT EVAPORATIVE VAPOR CONDENSERS



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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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ACCEPTANCE TEST CODE for EVAPORATIVE VAPOR CONDENSERS

Section 1. Purpose

1.1 Purpose. The purpose of this Code is to specify the procedures, apparatus, and instrumentation to be used for testing and evaluating the performance of evaporatively cooled, mechanical draft, vapor condensers.

Section 2. Scope

2.1 Scope. This Code applies to single circuit, mechanical draft, evaporative vapor condensers. The level of accuracy provided by tests conducted in accordance with this code is satisfactory for thermal acceptance testing and for establishing or confirming commercial ratings of evaporative vapor condensers.

2.1.1 Exclusions. The standard does not apply to evaporatively cooled steam condensers.

Section 3. General Requirements

3.1 Flexibility. The limitations on operating conditions specified throughout this test code represent conditions that will produce the desired level of test accuracy. It is recognized these may not be attainable in all instances 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.

3.2 Other Uses. Although intended primarily for thermal acceptance testing or establishing commercial ratings, all or parts of this Code may be used for other purposes, such as determining any of the individual measurements described. It also may be used for verification testing of condenser product lines as part of a certification program, in which case references to the purchaser are not applicable.

3.3 Impartial Testing Service. It is the intention of the Cooling Technology Institute to provide independent third-party thermal performance tests. This means the testing agency must have no material or other interest in the outcome of the test. Accordingly, the CTI-licensed Test Agency referred to in this code shall have no connection with the manufacturer, the purchaser, or the Cooling Technology Institute, other than a contractual agreement with the CTI as a licensed testing agency. For the purposes of this code, the CTI-

licensed Test Agency is hereinafter referred to as the CTI.

3.3.1 Certain categories of business interests or activities may compromise the objectivity of an agency and are considered by the 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, the agency will be excluded from consideration. A partial listing of such business interests or activities includes:

- a) The manufacture, repair, replacement, or upgrade of evaporative condensers or components thereof.
- b) Operation or ownership of evaporative condensers related to primary income generating processes.

3.3.2 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. Examples of such situations include, but are not limited to:

- a) Performing evaporative condenser 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 evaporative condenser manufacturer, constructor, or supplier of components or equipment on a particular condenser to be tested. (A conflict of interest shall not exist if the testing agency has conducted independent testing of other evaporative condensers for condenser owners, manufacturers, constructors, or suppliers of components and equipment).

3.4 Units of Measure. This standard is written in Primary Rational SI (International System of Units) units with secondary I-P (Inch-Pound) units. For full details

on appropriate conversions between I-P and SI units refer to CTI Bulletin STD-145 (95).

3.5 Test Results and Post Test Uncertainty Analysis. The test results obtained through the use of this code are the best available indication of the performance of the tested unit and are those that shall be compared with the guaranteed/rated performance. No adjustment shall be made to the results for test uncertainty.

A post test uncertainty analysis (see Section 5.4) can serve to evaluate the quality of the test and as a basis to accept or reject the test itself. If an uncertainty analysis is desired, this should be stipulated and agreed to by all parties prior to the test since this analysis requires certain additional data be recorded.

3.6 Test Tolerance. The acceptance criteria for the test and/or any allowable test tolerances shall be established by the parties to the test, prior to the test.

Section 4. Definitions and Symbols

4.1 Definitions. The terms used in this code follow the definitions in the current edition of CTI Bulletin NCL-109 and/or ASHRAE *Terminology of Heating, Ventilation, Air Conditioning, & Refrigeration*, unless otherwise specified in this section.

Capacity: The capacity of the evaporative, vapor condenser shall be expressed in terms of Total Heat Rejection Effect in kW (Btuh) for a specific Process Fluid at a specific condensing temperature and specific entering air wet-bulb temperature.

Condensing Temperature: the saturation temperature of the process fluid, expressed in °C (°F) corresponding to the pressure at the inlet(s) of the condenser heat exchanger. For zeotropic refrigerants, it is the arithmetic mean of the dew point and the bubble point.

Mechanical-Draft, Evaporative Vapor Condenser: A unit comprising a mechanical means for air circulation, a water circulation and distribution system, and a heat transfer means by which heat is transferred from a Process Fluid vapor to water and air. The purpose of the unit is to condense the Process Fluid vapor by rejecting heat to the water and air circulating over the heat transfer surface, thereby causing evaporation of the water, an increase in the enthalpy of the air, and a decrease in the enthalpy of the Process Fluid.

Process Fluid: The fluid of known physical and thermodynamic properties flowing through the

internal side of the condenser heat exchanger where it changes state from a vapor to a liquid as it gives up heat to the recirculating water and air on the external side of the exchanger.

Purchaser: The agency issuing the purchase order for the Evaporative Condenser and/or the acceptance test, usually the owner or an agency working on his behalf.

Single Circuit: A vapor condenser with one or more tube bundles (coils) connected solely to a common vapor inlet conduit and condensate outlet conduit.

Subcooling: The difference in temperature, in °C (°F), between the saturation temperature corresponding to the measured pressure of the Process Fluid condensate as it leaves the condenser and the measured temperature at the same point.

Superheat: The difference in temperature, in °C (°F), between the measured temperature and the saturation temperature corresponding to the measured pressure of the Process Fluid vapor as it enters the condenser.

Total Heat Rejection Effect: Total heat rejection effect is the rate of total heat removal from the Process Fluid. It is equal to the product of the mass flow rate of the Process Fluid and the enthalpy difference between the vapor entering the condenser and the liquid condensate leaving the condenser, expressed in kW (Btuh).

4.2 Symbols. The symbols used in this Code are identified in the following tabulation (some additional symbols are listed independently in the appendices).

Symbol	Description and Units of Measure
C_{cond}	= Condenser Capability, expressed as a percentage of design total heat rejection.
c_p	= Specific Heat of Water at constant pressure, kJ/kg · °C, (Btu/lbm · °F)
C_{units}	= A correction for units of measure equal to 1.0 for SI and 3412 for IP.
G	= Mass flow rate of dry air through the condenser, kg/s (lbm/h).
G_d	= Design value of the mass flow rate of dry air through the condenser, kg/s (lbm/h)

Symbol **Description and Units of Measure**

G_t	= Test value of the mass flow rate of dry air through the condenser, kg/s (lbm/h).
h	= Enthalpy, kJ/kg (Btu/lbm).
h_1	= Enthalpy of Process Fluid entering the Condenser, kJ/kg (Btu/lbm).
h_2	= Enthalpy of the Process Fluid leaving the Condenser, kJ/kg (Btu/lbm).
h_a	= Enthalpy of air, kJ/kg (Btu/lbm).
$h_{a,1}$	= Enthalpy of air entering the condenser, kJ/kg (Btu/lbm).
$h_{a,2}$	= Enthalpy of air leaving the condenser, kJ/kg (Btu/lbm).
h_{a-i}	= Enthalpy of the air entering the condenser, kJ/kg (Btu/lbm).
h_{a-o}	= Enthalpy of the air leaving the condenser, kJ/kg (Btu/lbm).
h_{w-mu}	= Enthalpy of water at the make-up water temperature, kJ/kg (Btu/lbm).
h_{w-sp}	= Enthalpy of water at the temperature of the condenser recirculating water, kJ/kg (Btu/lbm).
KWl_{fm}	= Electric power input to fan motor, kW.
KWl_{pm}	= Electrical power input to the recirculating water pump motor, kW.
$\dot{m}_{mu}$	= Mass flow rate of make-up water, kg/s (lbm/h).
$\dot{m}_{PF,1}$	= Mass flow rate of Process Fluid as determined by the primary method, kg/s (lbm/h).
$\dot{m}_{PF,2}$	= Mass flow rate of Process Fluid as determined by the confirming method, kg/s (lbm/h).
$\bar{m}_{PF}$	= Average mass flow rate of Process Fluid through the condenser, kg/s (lbm/h).
P_{baro}	= Barometric Pressure, kPa (in. Hg).

Symbol **Description and Units of Measure**

$P_{1,P}$	= Pressure of Process Fluid vapor entering the condenser, Primary Measurement, kPa (psig).
$P_{1,C}$	= Pressure of Process Fluid vapor entering the condenser, Confirming Measurement, kPa (psig).
$P_{2,P}$	= Pressure of Process Fluid condensate leaving the condenser, Primary Measurement, kPa (psig).
$P_{2,C}$	= Pressure of Process Fluid condensate leaving the condenser, Confirming Measurement, kPa (psig).
$\dot{q}_c$	= Total heat rejection rate of the condenser, kW (Btu/h).
$\dot{q}_{mu}$	= Heat rejection rate effect due to make-up, kW (Btu/h).
Q_{air}	= Volumetric flow rate of air through the condenser fan(s), m ³ /h (ft ³ /min).
Q_{bd}	= Volumetric flow rate of blow-down, L/s (gpm).
Q_{mu}	= Volumetric flow rate of make-up, L/s (gpm).
$Q_{PF,1}$	= Volumetric flow rate of the Process fluid, L/s (gpm).
T_{bd}	= Temperature of blow-down water, °C (°F).
$T_{db,1}$	= Average dry-bulb temperature of air entering the condenser, °C (°F).
$T_{db,2}$	= Average dry-bulb temperature of air leaving the condenser, °C (°F).
T_{mu}	= Temperature of make-up water entering the condenser, °C (°F).
$T_{PF,sat}$	= Saturation temperature of Process Fluid vapor corresponding to the pressure at the condenser inlet, °C (°F).
$T_{PF,1}$	= Temperature of Process Fluid vapor entering the condenser, °C (°F).

<u>Symbol</u>	<u>Description and Units of Measure</u>
$T_{PF, 2,P}$	Temperature of Process Fluid condensate leaving the condenser, Primary Measurement °C (°F).
$T_{PF, 2,C}$	Temperature of Process Fluid condensate leaving the condenser, Confirming Measurement °C (°F).
T_{rw}	Temperature of the recirculating water measured at the discharge of the recirculating pump, °C (°F).
$T_{wb, 1}$	Average Wet-Bulb temperature of air entering the condenser, °C (°F).
$T_{wb, 2}$	Average Wet-Bulb temperature of air leaving the condenser, °C (°F).
$\dot{W}_{fm}$	Fan driver output power, kW (bhp).
$\dot{W}_{pm}$	Spray water pump motor output power, kW (bhp).
Y	Exponent relating fan driver output power to condenser capacity. Limited in value such that: $0.15 \leq Y \leq 0.33$
η_{fm}	Efficiency of the fan driver, expressed as a decimal fraction.
η_{pm}	Efficiency of the recirculating water pump motor, expressed as a decimal fraction.
$v_{a, 1}$	Specific volume of air entering the condenser, m ³ mixture/kg dry air (ft ³ mixture/ lbm dry air).
$v_{a, 2}$	Specific volume of air leaving the condenser, m ³ mixture/kg dry air (ft ³ mixture/ lbm dry air).
ρ_d	Density of air entering the fan(s) at design operating conditions, kg mixture/m ³ (lbm mixture/ft ³)
$\rho_{PF, 1}$	Density of Process Fluid at primary flow measurement point, kg /m ³ (lbm /ft ³)
ρ_t	Density of air entering the fan(s) at measured test conditions, kg mixture/m ³ (lbm mixture/ft ³)

<u>Symbol</u>	<u>Description and Units of Measure</u>
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ρ_w = Density of water at temperature at point of interest, kg /m³ (lbm /ft³)

Section 5. Conditions of Test

5.1 Conduct of Test. The test shall be conducted by the CTI in the presence of authorized representatives of the purchaser and the manufacturer, 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 condenser and prepare it for the test and the notice shall include adequate time for that to be done. In no case shall any directly involved party be barred from the test site. Acceptance test(s) shall be conducted within 12 months after the installation/structural completion of the condenser unless otherwise stipulated by the contract between the purchaser and manufacturer.

5.2 Condition of Equipment. At the time of the test the evaporative condenser(s) shall be installed in accordance with the manufacturer's piping and siting recommendations and in good operating condition.

a) The system shall have been purged to reduce/eliminate non-condensables to an acceptable level (see Appendix G).

b) The water recirculating and distribution system shall be essentially clear and free of foreign materials that may impede the normal water flow.

c) Mechanical equipment shall be in good working order. Fans shall be rotating in the correct direction, with proper orientation of leading and trailing edges. The fan blades shall be at a uniform angle with the fan(s) running at a speed that will produce an operating power level within ± 10 percent of the specified fan driver power output. In addition, centrifugal fans shall be free of foreign material and properly secured to the shafts.

d) Drift eliminators, if applicable, shall be essentially clear and free of algae, debris, or other deposits that could impede the normal flow of air.

e) Heat exchanger surfaces and, if applicable, fill shall be essentially free of scale, dirt, oil, and other foreign debris that would affect the heat transfer and obstruct the flow of air or water. If the need is established, these surfaces shall be cleaned by commercially acceptable methods.

f) Water in the cold water basin shall be at normal operating level and shall be maintained substantially constant during the test to ensure

proper air flow and distribution through the unit.

g) Make-up and/or blow-down streams may be stopped during the test if other test condition requirements are not adversely affected.

h) Representatives of the purchaser and the manufacturer shall agree prior to initiating the test that the cleanliness of the equipment is within the tolerance specified by the manufacturer. Prior establishment of cleanliness criteria is recommended.

5.3 Operating Conditions. The test shall be conducted within the following limitations:

5.3.1 The wet-bulb and dry-bulb temperatures shall be the inlet values, measured in accordance with Paragraph 6.5.5 of this code.

5.3.2 The wind velocity shall be measured in accordance with Paragraph 6.7 of this code, and shall not exceed:

a) average wind velocity....4.5 m/s (10 mph)

b) one-minute duration.....7.0 m/s (15 mph)

5.3.3 For Acceptance Tests, the following deviations from design conditions shall not be exceeded:

Wet-bulb temperature..... $\pm 8.5^{\circ}\text{C}$ (15°F)

Dry-bulb temperature* ... $\pm 14.0^{\circ}\text{C}$ (25°F)

Total Heat Rejection (Load)..... $\pm 20\%$

Fan driver output power..... $\pm 10\%$

Circulating Pump output power

or pressure at distribution

inlet connection $\pm 10\%$

Barometric Pressure ± 3.5 kPa (1 in. Hg)

* If applicable

5.3.4 The Process Fluid vapor to be condensed shall be distributed to all operating cells as recommended by the manufacturer. For multi-cell condensers, one or more cells may be shut down with the heat exchangers and water distribution systems valved out, provided the flow rates of vapor and spray water to each operating cell are within the allowable limits. (For the purposes of this Code, a "cell" is defined as the smallest subdivision of the condenser, 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 water distribution systems).

5.3.5 The quality of the spray water recirculating

over the heat exchanger shall be limited as follows:

a) total dissolved solids shall not exceed 5,000 ppm or 1.1 times the design concentration.

b) oil, tar, or fatty substances shall not exceed 10 ppm 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.

5.3.6 When multiple condensers employ a common remote sump for the spray water, individual units/cells can be tested only if:

a) the unit/cell to be tested is the only unit operating under load with spray water circulating. Or . . .

b) the remote sump tank can be effectively partitioned such that spray water from other, operating units does not mix with the spray water of the unit under test.

5.4 Test Uncertainty. The overall test uncertainty is a measure of the quality of the test itself and depends on the type, number, and accuracy of instruments used for the various measurements, the scatter in the measured data, and the stability of the test conditions. Details on the recommended method for evaluation of overall test uncertainty are presented in ASME PTC-19.1 "Measurement Uncertainty".

Additionally, "Test Uncertainty" shall not be construed as a test tolerance nor shall it be used to adjust test results or guarantees.

Section 6. Instruments and Measurements

6.1 General. The single most important aspect in the selection and application of test instruments and instrument systems is to achieve the required level of accuracy in each variable or parameter measurement. To this end, precision, automated, electronic data acquisition shall be used to measure and record certain test parameters as further specified in this code. However, this code is not to be construed as preventing the use of advanced technologies or methods of measurement not described herein, provided the accuracy requirements of this code are achieved by the alternative method.

Also, it is **highly recommended** that provisions for instrumentation (thermometer wells, pressure taps, flow meter locations, etc.) be incorporated into the design and construction of the evaporative condenser system. Back fitting an existing system will be more expensive



and time consuming (See Figures 1 and 2 on page 8 and Appendix C).

6.2 Calibration. All instruments and instrument systems used on a test shall be calibrated and approved by the CTI prior to the test. Calibrations shall be traceable to primary or secondary standards calibrated by the U.S. National Institute of Standards Technology (NIST), other recognized national laboratories or derived from accepted values of natural physical constants.

6.2.1 Re-calibration. Instruments shall be re-calibrated regularly, at intervals no greater than those listed in Table 1. An instrument shall also be re-calibrated whenever it is damaged or its accuracy is called into question for any other reason. Additionally, immediately prior to the test, on site comparisons shall be made of all temperature sensors, after all wiring connections are made. If in doubt, a temperature sensor will be compared to another similar sensor and replaced if it is outside the accuracy specified for the appropriate measurement.

Table 1. Frequency of Calibration

Instrument	Minimum Frequency of Calibration
Temperature Sensors	Within 3 months prior to use.
Pressure Sensors	Within 3 months prior to use.
Flow Meters	Annually
Electric Power Meters	Annually
Wind Velocity Meters	Annually

Alternatively, at the request and expense of the test purchaser, any and all instrumentation used on a test can be calibrated before and after a test.

6.2.2 Documentation. The test agency shall have a written procedure for calibrating each type of instrument and shall maintain records showing the calibration history for each instrument, available upon request to the parties to the test.

The identification and location of each instrument used on the test shall be recorded and included in the test report so the calibration date and history can be traced.

6.3 Water Flow Measurements. Measurement of water flow rates may be made using any of the CTI approved methods specified in this code and/or CTI Bulletin STD-146. The selection of the method and location of measurement will depend upon the nature of the installation and the criticality of the measurement to the test result.

Instruments for measuring make-up and/or blow-down flow rates, if these are not stopped for the duration of the test, shall be accurate to $\pm 3.0\%$ of the quantity being measured.

6.4 Process Fluid Flow Rate Measurement. Process Fluid flow rates shall be measured with calibrated instruments accurate to $\pm 2.0\%$ of the quantity being measured, after applying such adjustments and corrections as are necessary to account for the temperature and physical properties of the Process Fluid.

6.4.1 Instruments. Acceptable instrument systems shall include orifice plates, venturies, and nozzles, as outlined in the latest edition of the applicable ASME code, coupled to transducers for automated, electronic data acquisition and other flowmeters that demonstrate the ability to measure flow rate precisely and accurately. These include, but are not limited to, Coriolis, magnetic, turbine, and transient time ultra sonic meters with their associated electronic processing systems.

6.4.2 Inspection and Installation The instruments, whether temporarily or permanently installed, shall be inspected prior to the test for dimensional conformity and functionality. They shall be installed in accordance with the guidelines in ASME PTC-19.5, *Application, Part II of Fluid Meters: Interim Supplement on Instruments and Apparatus*, Appendix C of this standard or other recognized national standards, as applicable.

6.4.3 Condensate Meter For measuring condensate flow, the flow meter shall be installed in a straight length of pipe, free of valves or fittings, extending **a minimum** of twenty pipe diameters (20D) in length. The flow meter shall be installed no less than fifteen diameters (15D) downstream and five diameters (5D) upstream of any valves or fittings, according to Figure 2.

The straight length of pipe must be fully flooded with sufficient liquid head (1 meter [36"] minimum) to overcome any pressure drop created by the flowmeter without flashing the condensate. See Appendix C, Figures C-1 through C-4 for recommended locations of condensate flowmeters.

6.5 Temperature Measurements. Temperature measurements shall be made using the instruments specified by this code for the measurement to be made in accordance with methods prescribed in ASME PTC-19.3 *Instruments and Apparatus, Part 3, Temperature Measurement* or other recognized national standards. All temperature measurement devices shall meet the following requirements: