

COOLING TECHNOLOGY INSTITUTE

TEST CODE FOR AIRCOOLED 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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TEST CODE for AIRCOOLED CONDENSERS

Section 1. Introduction

1.1 Scope This document details the measured test parameters, instrumentation, test measurements and data reduction procedure required for determination of the thermal capability of a dry, air-cooled steam condenser (ACC). The procedure focuses on contractual acceptance testing of new units, but the same procedure may be used for performance testing of an existing unit.

1.2 Basis Several resources have been used in the preparation of this code. These are:

- VGB Guideline for Acceptance Test Measurement and Operation Monitoring for Air Cooled Condensers (1997)
- Code of Practice for Acceptance and Operating Tests of Air Cooled Steam Condensers (published by the Association of German Electricity Supply Authorities in 1965)
- ASME PTC 12.2 Steam Surface Condensers
- CTI ATC-105 Acceptance Test Code for Water Cooling Towers (2000)
- ASME PCT-23 Atmospheric Water Cooling Equipment

1.3 Test Plan A test plan is a convenient vehicle for specification of responsible test participants, required preparations, measurement location, test instrumentation, required adjustments to plant operations, acceptable test conditions, anticipated deviations from the test code, calculation procedures, and expected test uncertainty. As an example, the measurement of steam flow and the estimation of steam quality will require the use of plant instruments, particularly flow elements. It is vital that such instruments be identified prior to the test so that any necessary calibrations can be performed. In addition, measurement of condensing pressure requires the installation of basket tips, which may be different in number and location than those used by the plant for monitoring purposes. The preparation of a test plan, approved by manufacturer and the ACC prior to the test, is highly recommended.

Impartial Testing Service - It is the intention of the Cooling Technology Institute to provide independent third-party thermal performance testing. This means that any situation in which a testing agency has a material or other interest in the outcome of the tests must be avoided. The CTI-licensed Test agency referred to in this code shall have no connection, other than contractual, with the manufacturer, the purchaser or the Cooling Technology Institute.

System of Units - This standard is written in System International (SI) Units with secondary inch-pound (I-P) units. For conversion factors between I-P and SI units, refer to CTI Bulletin STD-145.

1.4 Definitions and Nomenclature

Capability - a measure of the thermal capacity of the condenser expressed as a ratio between the design steam flow and the predicted steam flow at test conditions.

Condenser pressure - the steam pressure at the boundary of the condenser.

Predicted steam flow - the steam flow rate predicted by the manufacturer for a given set of test conditions.

Nomenclature

A	=	area, m ² (ft ²)
C	=	Condenser capability (%)
F _c	=	correction factor from test to guarantee conditions
NTU	=	number of heat transfer units
P	=	pressure, Pa (in Hg, psia)
Q	=	heat transfer rate, Watts (Btu/hr)
T	=	Temperature, °C (°F)
U	=	overall heat transfer coefficient, W/m ² /°C (Btu/hr/ft ² /°F)
$\dot{V}$	=	volumetric flow rate m ³ /s (ft ³ /min)
W	=	power, Watts (hp)
X	=	steam quality
z	=	wind speed, m/s (mph)
c _p	=	heat capacity at constant pressure, kJ/kg/°C (Btu/lbm/°F)
h	=	specific enthalpy, kJ/kg (Btu/lbm)
m _k	=	exponent for the correction of test fan motor power guarantee conditions
u	=	wind speed m/s (mph)
ΔT_{lm}	=	log mean temperature difference, °C (°F)
Φ	=	condenser effectiveness
Γ	=	condenser characteristic parameter
α	=	film heat transfer coefficient, W/m ² /°C (Btu/hr/ft ² /°F)
ρ	=	density, kg/m ³ (lbm/ft ³)

Subscripts

G	=	guarantee
P	=	predicted
T	=	test
M	=	measured
i	=	inlet
s	=	condensing steam

Superscripts

c	=	corrected value
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Section 2. Conditions of Test

2.1 Test Witnesses For acceptance testing, representatives of the owner and condenser manufacturer shall be given permission, opportunity and adequate notice to inspect the ACC and prepare the ACC for the test. In no case shall any directly involved party be barred from the test site.

2.2 Conditions of the Equipment

At the time of the test, the ACC shall be in good operating condition.

- a) Steam duct and condensate piping systems shall be essentially clear and free of foreign materials that may impede the normal flow of steam and condensate.
- b) Mechanical equipment, including fans, gear boxes, motors, pumps, air ejectors, etc., shall be clean and in good working order. Fans shall be rotating in the correct direction, with proper orientation of the leading and trailing edges. Fan blade pitch shall be set to a uniform angle that will yield within $\pm 10\%$ of the guarantee fan driver input power when corrected for the air density at the test condition. Variable frequency drives, if present, must be put into bypass (preferred), or set to 100% of rated speed.
- c) Air in-leakage must be such that the vacuum equipment has at least 50% excess holding capacity during the test.
- d) ACC air inlet perimeter area and discharge area shall be essentially clear and free from temporary obstructions that may impede normal airflow.
- e) The air side of the ACC fin tube bundles shall be essentially free of foreign material, such as pollen, dust, oil, scale, paper, animal droppings, etc.
- f) Water level in the condensate hotwell tank shall be at the normal operating level.
- g) Representatives of the ACC purchaser and manufacturer shall agree prior to commencement of testing that the cleanliness and condition of the equipment is within the tolerance specified by the manufacturer. Prior establishment of cleanliness and condition criteria are strongly recommended.
- h) All emergency drain lines and all bypass lines which have the potential for delivering superheated steam to the condenser shall be isolated. A closed valve shall be considered adequate isolation.

2.3 Operating Condition

2.3.1 The test shall be conducted while operating as close to the operation/guarantee point(s) as possible. In any event, the test shall be conducted within the following limitations:

2.3.2 The test dry-bulb temperature shall be the inlet value, measured in accordance with paragraph 3.4 of this test procedure.

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

2.3.4 Average wind velocity shall be less than or equal to 4.5 m/s (10 miles per hour).

a) One minute duration velocity shall be less than 7 m/s (15.6 miles per hour).

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

a) Dry-bulb temperature $\pm 10^\circ\text{C}$ from design (18°F) but greater than 5°C (41°F).

b) Condensate Mass Flow $\pm 10\%$ of the design value.

c) Fan motor Input Power $\pm 10\%$ of the design value after the air density correction. (Eq. 4-7)

2.3.4 Steam turbine exhaust steam shall be distributed to all modules as recommended by the manufacturer. For the purposes of the Code, a "module" is defined as the smallest subdivision of the ACC, bound externally by fin tube bundles and internally by partition walls, which can function as an independent unit. Each module generally has a single fan.

2.3.5 There shall be no rain during the test period nor in the one hour period preceding the test period.

2.3.6 Steady state operation (constant condensate mass flow as defined in section 2.4.1) of the ACC shall be achieved at least one hour before and shall be maintained during the test periods.

2.4 Constancy of Test Conditions

For a valid test, variations in test conditions shall be within the following limits:

2.4.1 Inlet dry-bulb temperature shall not vary by more than 3°C (5.4°F) during the test. Variation is defined as the slope of the inlet dry-bulb temperature with time the test run multiplied by the time period of the test.

2.4.2 The initial temperature difference (ITD, defined as the difference between the condensing steam temperature, as calculated from the condenser pressure at the test boundary, and the inlet air temperature and the condensing steam temperature) shall not vary by more than 5% of the ITD during the test period. The variation between the maximum ITD and the minimum ITD shall not be more than 10% of the average ITD during the test period.

2.5 Duration of the Test

After reaching steady state conditions, the requirements for the test duration shall be at least one hour. Longer test intervals are acceptable provided the constancy of test conditions is observed.

2.6 Frequency of Readings

Readings shall be taken at regular intervals and recorded in the units and to the number of significant digits shown in Table 2.0.

Table 2.0 Measurement Frequency			
Measurement	Minimum Readings per hour per station	Unit	Recorded to Nearest
ACC Condensate Mass Flow	60	kg/h (lb/h)	0.1%
Condensate Hotwell Tank Level	5	M (ft)	0.01 (0.03)
Exhaust Steam Pressure	60	kPa (in.HgA)	0.005 (0.01)
Exhaust Steam Temperature (for comparison)	60	°C (°F)	0.05 (0.1)
Inlet Air Dry-bulb Temperature	60	°C (°F)	0.01 (0.01)
Atmospheric Pressure	1	kPa (in. Hg)	0.2 (0.05)
Ambient Wind Velocity	60	m/s (mph)	0.1 (0.2)
Fan Power at Switchgear	1	kW (HP)	0.5%

2.7 Number of Tests

Even when tested under the guidelines specified in section 2.3, the apparent performance of air cooled condensers may vary with the following environmental conditions:

- wind speed
- wind direction
- atmospheric stability

To decrease the possibility of an anomalous test result, it is required that at least six tests be performed over a two day period. The capability of the condenser shall be the average of the tests conducted with test conditions within the limits specified in this Code.

Section 3.0. Test Measurements

The objective of the parameter measurements is to accurately and reproducibly measure the thermal performance of the air cooled condenser for comparison against the guarantee provided by the manufacturer. The primary parameters to be measured are:

- condenser pressure
- steam quality (content)
- condensate flow rate
- condensate tank water level
- inlet air dry bulb temperature
- barometric pressure
- fan motor input power
- wind speed

It is recommended that the following parameters be acquired for reference purposes:

- exhaust steam temperature
- condensate temperature
- air removal rate
- wind direction

3.1 Condenser Pressure

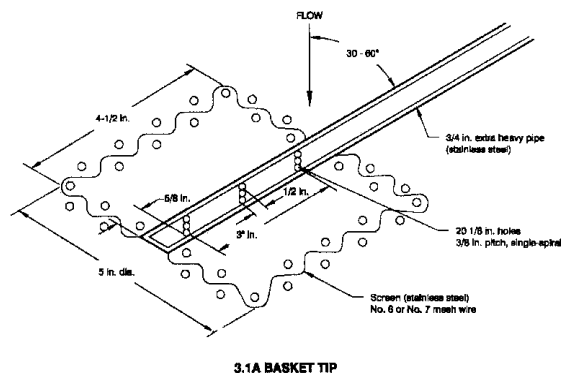
3.1.1 Condenser pressure should be measured at the boundary of supply of the condenser manufacturer unless another location is agreed upon by the parties to the test. Four measurement points per inlet are required unless the

total flow for an inlet is less than five percent of the total. For inlet flows with less than 5 percent of the total steam flow, one pressure measurement is required. Steam inlets with less than 1 per cent of the total steam flow need not be instrumented.

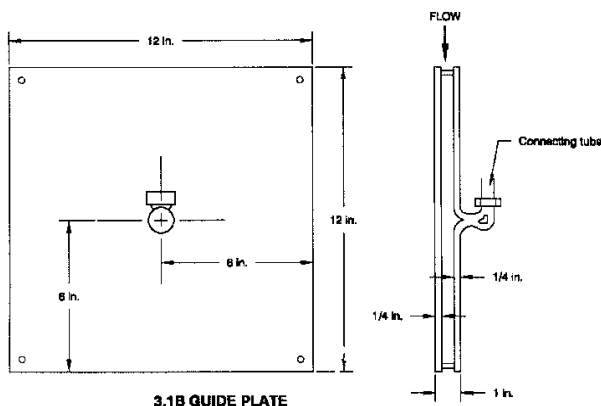
3.1.2 For air cooled condensers with multiple steam inlets, the mass weighted average absolute pressure of the instrumented inlets shall be used as the condenser pressure on lookup charts, tables, and curves.

3.1.3 The pressure measurement points shall be located at positions 90° apart around the steam inlet. Pressure ports shall be bored holes in the wall of the steam inlet connected to basket tips or baffle plates as illustrated in Figure 3.1 A and B. Separate pressure sensors shall be connected to each port. Provisions should be made for purging all pressure connections to keep them free of condensate.

3.1.4 Pressure sensors shall have a calibrated accuracy of 35 Pa (0.005 psia) or less. Steam temperature measurements should be taken in the thermal wells in the vicinity of the pressure measurements.



3.1A BASKET TIP



3.2 Steam Quality (Steam Content)

Since the steam at the condenser inlet will be in the wet steam range, measurement of the temperature and pressure is insufficient to determine its enthalpy. At present there is no acceptable method for measuring the quality directly, thus the parties to the test must agree on a method for calculating this value. Some suggested methods are:

a) Energy balance – If the temperature, pressure and flow rate of all steam flows into the steam turbine are measured, as well as turbine power output and generator losses, it is possible to determine the enthalpy of the exhaust steam by an energy balance. This method requires many measurements which are unlikely to be available unless a concurrent steam turbine test is being performed. If this method is used, the values of the steam flows should be verified performing a mass balance around the condenser and steam turbine.

b) Cycle Model-With sufficient information from the steam turbine manufacturer, it is possible to construct a cycle model for the steam turbine. Such a model can then be used to construct correction curves for steam quality based on measured cycle variables. Such a cycle model should be verified using the steam turbine manufacturer's thermal kit.

3.3 Condensate Flow

3.3.1 The condensate flow shall be measured downstream of the condensate pumps. The recommended devices for measuring condensate flow are differential pressure producers (orifice plates, flow nozzles, venturis). The calibration records and construction details of the flow element shall be made available to the parties to the test. The pressure transmitter reading the differential pressure shall be calibrated prior to the test to an accuracy of not more than 0.25 percent of the expected differential at the design flow. The installation of the flow element shall conform to the specifications of ASME PTC 19.5 Flow Measurement. The flow element, as installed, shall have an accuracy of not more than 0.75 percent.

3.3.2 A time-of-flight ultrasonic flow meter may be used to measure the condensate flow rate by agreement

between the parties to the test. If used, the ultrasonic flow meter shall be calibrated in a pipe corresponding to the diameter and wall thickness of the pipe on which it will be installed. The calibration range shall cover the Reynolds number expected for the pipe at the design flow. The installation location shall have at least 16 pipe diameters of undisturbed length upstream of the meter and 4 pipe diameters of undisturbed length downstream of the meter.

Readings shall be taken at 6 positions 30° apart around the circumference of the pipe. These readings shall be averaged to obtain the condensate flow. If the high and low readings differ by more than 2 percent, the cause shall be investigated. Use of an ultrasonic flow meter will result in a higher uncertainty for the condensate flow measurement than if an inline flow element is used.

3.3.3 Steam flow to the condenser shall be calculated by a mass balance around the condenser with consideration of any liquid flow streams upstream of the measurement point and the change in level of the condensate tank during test. Design values may be used for those flow streams representing less than 3 percent of the design steam flow.

3.4 Inlet Air Temperature This code recommends the characterization of the performance of the air cooled condenser based on the inlet air temperature as opposed to the ambient air temperature. This recommendation is based on the following considerations:

- The results tend to be much more reproducible when the inlet air temperature is used as the basis for thermal evaluation. Air cooled condensers are subject to recirculation (the re-entrainment of the exhaust air into the air inlet) and interference from other heat sources in the area. Slight changes in the wind speed or direction can greatly affect the amount of this recirculation and interference, which greatly increases the scatter in the test results if performance is based on ambient air.
- The test result tends to be a fairer representation of the performance of the condenser. While the amount of recirculation is influenced by the condenser design chosen by the manufacturer, it is also governed by the siting of the condenser. Other structures or uneven topography in the vicinity can influence the amount of recirculation.
- Ambient temperature in a plant can be difficult to measure. It is difficult to find a location that is not influenced by other heat sources. Inlet temperatures to other equipment such as turbines or boilers, are greatly influenced by heat sources in their surroundings. Temperature measurements at these locations should never be used to characterize air cooled condenser performance.

3.4.1 Inlet dry bulb temperature shall be measured with a four wire RTD with a calibrated accuracy of 0.05°C (0.1°F). These sensors shall be placed at the