ASME PTC 30.1-2007

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Air-Cooled Steam Condensers

Performance Test Codes

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The American Society of Mechanical Engineers

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This Code will be revised when the Society approves the issuance of a new edition. There will be no addenda issued to ASME PTC 30.1-2007.

ASME issues written replies to inquiries concerning interpretations of technical aspects of this document. Periodically certain actions of the ASME PTC Committee may be published as Code Cases. Code Cases and interpretations are published on the ASME Web site under the Committee Pages at http://cstools.asme.org as they are issued.

The American Society of Mechanical Engineers
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CONTENTS

Notice		v
Foreword		vi
Committee Roster		vii
Correspondence With the PTC 30.1 Committee		viii
Section 1	**Object and Scope**	1
1-1	Object	1
1-2	Scope	1
1-3	Uncertainty	1
Section 2	**Definitions and Descriptions of Terms**	3
2-1	Symbols	3
2-2	Definitions	3
Section 3	**Guiding Principles**	8
3-1	Introduction	8
3-2	Agreement Among Parties to the Test	8
3-3	Uncertainty Analysis	9
3-4	Test Preparations	10
3-5	Arrangement of Test Apparatus	10
3-6	Test Personnel	12
3-7	Method of Operation During the Test	12
3-8	Conduct of Test	12
Section 4	**Instruments and Methods of Measurement**	15
4-1	Introduction	15
4-2	Measurement of Environmental Effects	15
4-3	Location of Test Points	15
4-4	Instrumentation and Methods of Measurement	17
Section 5	**Computation of Results**	19
5-1	General	19
5-2	Review of Test Data and Test Conditions	19
5-3	Reduction of Test Data	19
5-4	ACC Design Data	19
5-5	Particular Calculations at the Guarantee Point	20
5-6	Adjustment of Test Data to Guarantee Conditions	20
5-7	Condensate Temperature	21
5-8	Oxygen Content	21
5-9	Test Uncertainty	21
5-10	Uncertainty Analysis	22
Section 6	**Report of Results**	24
Figures		
3-5	Arrangement of Test Apparatus	11
4-4.1-1	Basket Tip	17
4-4.1-2	Guide Plate	17
Tables		
2-1	Symbols	4
3-2.2	Noncondensible Gas Load Limits	9

Nonmandatory Appendices

A	Sample Calculations of Performance	25
B	Description of Performance Curves	32
C	Uncertainty Analysis Example	38
D	Derivation of Exponents m_k and n	42
E	Calculation of the Steam Quality at Test Conditions	45
F	Test Calculations for Dissolved Oxygen Determination	47
G	Data Sheets	49
H	Reporting Form of Results of ACC Performance Test	54
I	Performance Monitoring	55
J	Routine Performance Test	58
K	Environmental Effects	59
L	Electric Power Line Losses	72

NOTICE

All Performance Test Codes must adhere to the requirements of ASME PTC 1, General Instructions. The following information is based on that document and is included here for emphasis and for the convenience of the user of the Code. It is expected that the Code user is fully cognizant of Sections 1 and 3 of ASME PTC 1 and has read them prior to applying this Code.

ASME Performance Test Codes provide test procedures that yield results of the highest level of accuracy consistent with the best engineering knowledge and practice currently available. They were developed by balanced committees representing all concerned interests and specify procedures, instrumentation, equipment-operating requirements, calculation methods, and uncertainty analysis.

When tests are run in accordance with a Code, the test results themselves, without adjustment for uncertainty, yield the best available indication of the actual performance of the tested equipment. ASME Performance Test Codes do not specify means to compare those results to contractual guarantees. Therefore, it is recommended that the parties to a commercial test agree before starting the test and preferably before signing the contract on the method to be used for comparing the test results to the contractual guarantees. It is beyond the scope of any Code to determine or interpret how such comparisons shall be made.

FOREWORD

The history of this performance test code started in 1960 when the Board on Performance Test Codes organized PTC 30 on Atmospheric Cooling Equipment. It was the first attempt by ASME to provide procedures for testing air-cooled heat exchangers. Except for a preliminary draft, the Code was not completed at that time due to the death of the Chair and he was its only Committee Member. In 1977 the Board decided to resume the effort to produce a performance test for air-cooled heat exchangers. Subsequently a committee was formed and developed an appropriate Code after several years. The title of the new Code was revised to "Air-Cooled Heat Exchangers" and on February 15, 1991, the Code was approved as an American National Standard.

The 1991 issue of that Code was a credit to those on the Committee. It was very comprehensive, erudite, and a definite contribution to the art of engineering. But it was infrequently used due to the difficulty of measuring the airflow through the equipment and other aspects of its application to the great variety of exchangers that existed and the minimal acceptance testing that was traditionally specified in the general heat exchanger industry.

During 2002, the Board on Performance Test Codes had taken notice that air-cooled steam condensers (ACCs) were being largely installed on power plants at an increasing rate throughout the country and the world. At that point in time, there were over 600 ACCs worldwide with more than fifty large applications of the technology in the United States. These machines are essentially enormous radiators served by a multiplicity of fans that, compared to water-cooled condensers, are relatively expensive and generally exhibit a poorer performance. They were being applied however in order to conserve water resources; to allow a particular plant to be located in water scarce regions; to reduce the aquatic and airborne environmental effects often associated with once-through or wet cooling towers; and to bring projects to completion quickly without having to address restrictive regulations related to any future use of cooling waters. In addition, because their size could be as big as an acre or more, it appeared there was there was no directly fitting test code that would allow a cost-effective, practical engineering performance test of the equipment. Thus, in November 2002, the Board on Performance Test Codes directed a committee be formed to update and/or produce a test code applicable to these air-cooled condensers. A large national Committee was convened the following year that was comprised of experts from manufacturing, utility-owners, test agency, academia, and consultants in the field.

Before the work of revising or drafting up a Code began, a careful review of PTC 30 was undertaken and some field-test experience with that Code was reported to the Committee. As a result, the Committee decided not to update the existing Code but rather to create a new Code expressly for the performance testing of the ACCs utilized on power plants. Hence, the existing Code was retained and a new Code was designated as PTC 30.1, Air-Cooled Steam Condensers.

The general focus of PTC 30.1 is acceptance testing. Recognizing, however, the importance of minimal turbine exhaust pressure on plant generation, the Committee also featured two Appendices of the Code that address both methods of Performance Monitoring and Routine Performance Testing. These appendices contain pragmatic techniques that use lesser accuracy instrumentation and procedures that will allow plant personnel to maintain the lowest turbine backpressures without the higher costs or engineering efforts associated with acceptance testing.

This edition of PTC 30.1, Air-Cooled Steam Condensers was approved by the Performance Test Code Committee 30.1 on April 30, 2007 and by the Performance Test Codes Standards Committee on April 30, 2007, and approved and adopted as a Standard practice of the Society by action of the Board on Standardization and Testing on June 7, 2007. This edition was approved by the American National Standards Institute on August 17, 2007.

ASME PTC COMMITTEE
Performance Test Codes

(The following is the roster of the Committee at the time of approval of this Standard.)

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CORRESPONDENCE WITH THE PTC 30.1 COMMITTEE

General. ASME Codes are developed and maintained with the intent to represent the consensus of concerned interests. As such, users of this Code may interact with the Committee by requesting interpretations, proposing revisions, and attending Committee meetings. Correspondence should be addressed to

Secretary, PTC 30.1 Standards Committee
The American Society of Mechanical Engineers
Three Park Avenue
New York, NY 10016-5990

Proposing Revisions. Revisions are made periodically to the Code to incorporate changes that appear necessary or desirable, as demonstrated by the experience gained from the application of the Code. Approved revisions will be published periodically.

The Committee welcomes proposals for revisions to this Code. Such proposals should be as specific as possible, citing the paragraph number(s), the proposed wording, and a detailed description of the reasons for the proposal, including any pertinent documentation.

Proposing a Case. Cases may be issued for the purpose of providing alternative rules when justified, to permit early implementation of an approved revision when the need is urgent, or to provide rules not covered by existing provisions. Cases are effective immediately upon ASME approval and shall be posted on the ASME Committee Web page.

Requests for Cases shall provide a Statement of Need and Background Information. The request should identify the Code, the paragraph, figure or table number(s), and be written as a Question and Reply in the same format as existing Cases. Requests for Cases should also indicate the applicable edition(s) of the Code to which the proposed Case applies.

Interpretations. Upon request, the PTC 30.1 Committee will render an interpretation of any requirement of the Code. Interpretations can only be rendered in response to a written request sent to the Secretary of the PTC 30.1 Standards Committee.

The request for interpretation should be clear and unambiguous. It is further recommended that the inquirer submit his/her request in the following format:

Subject:	Cite the applicable paragraph number(s) and the topic of the inquiry.
Edition:	Cite the applicable edition of the Code for which the interpretation is being requested.
Question:	Phrase the question as a request for an interpretation of a specific requirement suitable for general understanding and use, not as a request for an approval of a proprietary design or situation. The inquirer may also include any plans or drawings that are necessary to explain the question; however, they should not contain proprietary names or information.

Requests that are not in this format will be rewritten in this format by the Committee prior to being answered, which may inadvertently change the intent of the original request.

ASME procedures provide for reconsideration of any interpretation when or if additional information that might affect an interpretation is available. Further, persons aggrieved by an interpretation may appeal to the cognizant ASME Committee or Subcommittee. ASME does not "approve," "certify," "rate," or "endorse" any item, construction, proprietary device, or activity.

Attending Committee Meetings. The PTC 30.1 Standards Committee regularly holds meetings, which are open to the public. Persons wishing to attend any meeting should contact the Secretary of the PTC 30.1 Standards Committee.

AIR-COOLED STEAM CONDENSERS

Section 1
Object and Scope

1-1 OBJECT

This Code provides uniform test methods for conducting and reporting thermal performance characteristics of mechanical draft air-cooled steam condensers (ACC) operating under vacuum conditions.

This Code provides explicit test procedures to yield results of the highest levels of accuracy consistent with the best engineering knowledge taking into account test costs and the value of the information obtained from testing and practice currently available. This Code provides rules for conducting acceptance tests. It also provides guidelines for monitoring thermal performance and conducting routine tests.

The tests can be used to determine compliance with contractual obligations and the Code can be incorporated into commercial agreements. A test shall be considered an ASME Code Test only if the test procedures comply with those stipulated in this Code and the post-test uncertainty analysis results are in accordance with subsection 1-3.

1-2 SCOPE

This Code provides rules for determining the thermal performance of the referenced equipment with regard to the steam flow capability while meeting any applicable fan power guarantees. This steam flow capability may be alternatively expressed as a deviation from design flow capability, a deviation from design turbine backpressure, or as the absolute value of the steam turbine backpressure. This Code also provides procedures for assessing compliance to specified dissolved oxygen and specified condensate temperature. This Code does not address procedures for assessing noise.

The Code is not intended for tests of

(a) devices for which the process fluid is above atmospheric pressure

(b) devices for process fluids other than steam

(c) devices for single-phase process fluids

(d) wet surface air cooled condensers

(e) natural draft or fan-assisted air cooled condensers

(f) air-cooled condensers with inlet air conditioning in-service

The determination of special data or verification of guarantees that are outside the scope of this Code shall be made only with the written agreement of the parties to the test. The agreed methods of measurement and computation shall be defined in writing and fully described in the test report.

1-3 UNCERTAINTY

The explicit measurement methods and procedures have been developed to provide a test of the highest level of accuracy consistent with practical limitations for acceptance testing. Any departure from Code requirements could introduce additional uncertainty beyond that considered acceptable to meet the objectives of the Code.

The application of uncertainties to adjust test results is not part of this Code; the test results themselves provide the best indication of actual performance. The uncertainty is used to determine the quality of the test and reflects the accuracy of the test instrumentation and stability of the test conditions. Test tolerance, margin, and allowance are commercial matters that are not addressed by this Code.

The maximum uncertainties shown below are limits — not targets. A Code precept is to design a test for the highest practical level of accuracy based on current engineering knowledge. For a commercial test, this philosophy is in the best interest of all parties to the test. Deviations from the methods stated in this Code are acceptable only if it can be demonstrated to the test parties that the deviations provide equal or lower uncertainty in the calculated test result.

A pretest uncertainty analysis shall be performed to establish the expected level of uncertainties for the test, including an estimate of the random (precision) uncertainty based on experience.

A post-test uncertainty analysis is similarly required. The results of a thermal performance test, conducted in full compliance with the procedures and instrumentation specified in this Code, shall be considered valid if the calculated overall uncertainty in the thermal capability is less than ±4.0%. If the post-test uncertainty is greater than ±4.0%, then the test is not a Code test. In addition, the uncertainty of Code tests that determine the condensate temperature shall be less than ±0.3°C and Code tests that measure the dissolved oxygen in the condensate shall have an uncertainty of less than ±2.6 ppb.

Because of the variety of methods and instruments used in the conduct of performance tests, the test uncertainty must be determined by an uncertainty analysis based on ASME PTC 19.1 but specifically applied to the equipment indicated within this Code. It should be noted that the collection, reduction, and evaluation of thermal data are greatly facilitated through the use of a data acquisition system. The use of a data acquisition system is preferable to a manual recording system because a data acquisition system supports increased sampling frequency, increased number of test measurements, and the ability to scan more instruments that in combination will reduce the random error in the measurements.

Section 2
Definitions and Descriptions of Terms

2-1 SYMBOLS

The symbols listed in Table 2-1 are to be used unless otherwise defined in the text. Numerical constants used in the equations and examples in the Code, unless otherwise specified, are based on SI Units.

2-2 DEFINITIONS

The following terms are characteristic of air-cooled steam condensers and the requirements for testing them. For the definition of all other physical terms, or the description of the instruments used in this Code, refer to the literature and to ASME PTC 19.1, Test Uncertainty; ASME PTC 19.2, Pressure Measurement; and ASME PTC 19.3, Temperature Measurement.

acceptance test: the evaluating procedure to determine if a new or modified piece of equipment satisfactorily meets or exceeds its performance criteria, permitting the purchaser to "accept" it from the supplier.

accuracy: the closeness of agreement between a measured value and the true value.

adjustment:

(a) starting equipment, stopping equipment, or changing the set point of equipment during a test run.

(b) correction of test parameters to guarantee conditions.

air-cooled condenser (ACC): a heat exchanger using ambient air as the heat sink to absorb heat directly from steam at vacuum conditions, condensing the steam and recovering the condensate, as would be typically used in an electric power generating station.

air-removal system: a system of steam-jet air ejectors (SJAEs) and/or liquid-ring vacuum pumps (LRVPs) in any combination, intended to remove the noncondensibles and maintain the capability of the ACC and support operation of the vacuum deaerator. The air removal system is typically supplied and tested as part of the ACC.

ambient air temperature: the temperature of the air measured upwind of the ACC within its air supply stream.

ambient wind velocity: the speed and direction of the wind measured upwind of the ACC within its air supply stream.

area: the outside surface area, including tube surface and fin surface; the area used as the basis for heat-transfer calculations.

atmospheric pressure: force per unit area exerted by the atmosphere at the location of the ACC.

backpressure: see *condenser pressure.*

bias error: see *systematic error.*

calibration: the process of comparing the response of an instrument to a standard instrument over some measurement range and adjusting the instrument to match the standard, if appropriate.

cogeneration steam load: the portion of the steam generated in the unit that is diverted to a process unrelated to power generation. The diverted steam is not condensed in the ACC, and the condensate may or may not be returned to the condensate tank.

condensate pump: a pump that withdraws condensate from the condensate tank and discharges it to the boiler circuit, HRSG, or other components of the power cycle. Also called *condensate forwarding pump*. It is typically not supplied nor tested as part of the ACC.

condensate tank: a vessel at roughly the same pressure (vacuum) as the ACC that collects condensate returning from the heat transfer surfaces, plant drains, and makeup water. Also called *condensate receiver*. It is typically supplied and tested as part of the ACC.

condenser pressure: the absolute pressure at the prescribed location, typically at or near the steam turbine exhaust flange at which design and guarantee performance are to be achieved.

controlling guarantee case: that combination of thermal duty, condensing pressure, and inlet air temperature that dictates the design of the ACC. See para. 3-8.1.

corrected performance: performance parameter adjusted mathematically to a specified reference condition.

data acquisition system: a system by which substantially all of the test measurements are acquired and recorded electronically and stored directly in a computer.

deaerator: a device that removes dissolved oxygen from the makeup water.

design values: performance conditions upon which the design of the ACC is based and for which the performance of the ACC may be predicted.

exit air temperature: the temperature of the air leaving the ACC.

Table 2-1 Symbols

Symbol	Definition	SI Units	U.S. Customary Units
A	Heat transfer surface area	m^2	ft^2
b	Systematic uncertainty associated with each measured variable or parameter	. . .	. . .
c_p	Specific heat of air	kJ/kg-°C	Btu/lb-°F
C	Condenser capability	%	%
f	Electrical resistance factor for a wire	. . .	. . .
f_x, f_p, f_{fp}, f_{pc}	Correction factors	. . .	. . .
h	Coefficient of convective heat transfer	W/m^2-K	Btu/hr-ft^2-°F
h	Specific enthalpy	J/kg	Btu/lb
h_{fg}	Specific latent heat of vaporization	J/kg	Btu/lb
I	Electric current	Amp	Amp
ITD	Initial temperature difference	°C	°F
k	Tube wall thermal conductivity	W/m-K	Btu/hr-°F
$LMTD$	Log mean temperature difference	°C	°F
m	Number of measurement stations	. . .	. . .
$\dot{m}$	Mass flow	kg/s	lb/hr
m_e	Slope of the turbine expansion line	. . .	. . .
m, m_k	Reynolds number exponent of overall heat transfer coefficient (see Appendix D)	. . .	. . .
n	Reynolds number exponent of friction factor (see Appendix D)	. . .	. . .
N	Number of test runs	. . .	. . .
NTU	Number of heat transfer units	. . .	. . .
p	Pressure	kPa	psia, in. HgA
Q	Condenser heat load	W	Btu/hr
q	Volumetric flow rate for air	m^3/hr	ft^3/hr
R	Electric resistance	Ohm	Ohm
Re	Reynolds number	. . .	. . .

Table 2-1 Symbols (Cont'd)

Symbol	Definition	SI Units	U.S. Customary Units
R_f	Air-side fouling coefficient	m^2-K/W	hr-ft^2-°F/Btu
s	Specific entropy	kJ/kg-K	Btu/lbm-°F
S	Standard deviation	. . .	. . .
t	Student's t value	. . .	. . .
T	Temperature	°C	°F
U	Overall heat transfer coefficient	W/m^2-K	Btu/hr-ft^2-°F
U_{95}	Test uncertainty	. . .	. . .
v	Velocity	m/s	ft/sec
W	Fan power	W	hp
x	Steam quality	fraction	fraction
x	Value of a test parameter	. . .	. . .
z	Height	m	ft
β	Systematic error	. . .	. . .
Γ	"Gamma factor," a convenient function of NTU	. . .	. . .
δ	Tube wall thickness	m	ft
Δ	Differential	. . .	. . .
ϵ	Random error	. . .	. . .
η	Fan motor efficiency	. . .	. . .
θ	Sensitivity coefficient	. . .	. . .
ρ	Density	kg/m^3	lbm/ft^3
σ	Random uncertainty	. . .	. . .
Σ	Summation	. . .	. . .
Φ	"Performance coefficient," a convenient function of NTU	. . .	. . .

fan deck: the horizontal platform or barrier at or near the elevated plane of the fans. It may or may not provide for personnel access.

fan pitch: the angle of attack to which the fan blades are set, typically measured from the horizontal fan plane to the inclined chord of the fan blade at a designated measurement location on the fan blade.

fan speed: the number of revolutions of the fan per unit time.

forced draft: a mechanical-draft ACC in which the fans are located upstream of the heat transfer surface.

guarantee location: the physical location at which a guaranteed parameter is to be determined.

guarantee values: specified or predicted operating conditions for which the design of the ACC was guaranteed. Also called *guarantee point*, *case,* or *conditions.*

induced draft: a mechanical-draft ACC in which the fans are located downstream of the heat transfer surface.

influence coefficient: see *sensitivity factor.*

initial temperature difference (ITD): the difference between the saturated steam temperature at the condenser pressure and the inlet air temperature.

inlet air temperature: the temperature of the air entering the ACC, including the effect of any recirculation and/or interference.

instrument uncertainty: an estimate of the limit of the error of a measurement; the interval about the measurement that contains the true value for a given confidence level.

interference: the thermal contamination of ACC inlet air by a source extraneous to the ACC.

LMTD: log mean temperature difference, as computed from condenser heat load.

makeup water: water supplied to the deaerator or condensate tank by external systems to replace system losses due to boiler blow-down, drainage, leakage, and nonreturning cogeneration steam loads. Makeup water is typically assumed to be saturated with oxygen.

manual recording system: a system by which substantially all the measurements are observed and recorded manually in a test log, even if they are later entered into a computer for data reduction and analysis.

margin: the positive or negative limit surrounding an desired value, in which an acceptable result may lie.

measurement error: the true, unknown difference between the measured value and the true value.

measurement uncertainty: estimated uncertainty associated with the measurement of a process parameter or variable.

mechanical draft: a type of ACC in which the air flow is effected by fans. In the typical ACC, these are motor-driven axial fans.

multiparty test: performance test for an ACC where the results of the test are the substance of a contract. Typically, the parties are the Vendor and the Owner of the ACC. The testing agency is not one of the parties.

multiple-unit complex: a station in which there are several units, intended to be capable of simultaneous operation.

parameter: a physical quantity at a location. The parameter can be determined by measurement with a single instrument, by the average of several measurements of the same physical quantity, or by computation from measurements of other physical quantities.

parties to the test: those persons and companies interested in the results of the test. For an acceptance test, the parties are those individuals designated in writing by the Owners or the Vendors to make the decisions required in this Code.

performance monitoring: trending and evaluation of ACC performance during normal operation. See Nonmandatory Appendix I.

preliminary test run: a test run, with records, that serves to determine if equipment is in suitable condition to test, to check instruments and methods of measurement, to check adequacy of organization and procedures, and to train personnel.

random error: the true random error, which characterizes a member of a set of measurements. The error varies in a random, Gaussian (normal) manner, from measurement to measurement. Sometimes called *precision error.*

random uncertainty: an estimate of the limits of random error with a defined level of confidence (usually 95%).

recirculation: the flow of ACC exit air that is entrained into the ACC inlet air flow.

routine performance test: a test to provide the analytical basis for comparison of the current performance of an ACC with its design or like-new condition. See Nonmandatory Appendix J.

sensitivity factor: the ratio of the change in a result to a unit change in a parameter. Also called *sensitivity coefficient.*

single-party test: test of an ACC where the results of the test are not the substance of a contract. However, if a test agency performs the test on behalf of the party, the uncertainty of the test may be the substance of the contract with the test agency.

stabilization period: the time period, prior to a test run, necessary to establish minimally changing operating conditions that are required for a valid performance test.

steam duct: the duct that conveys the entire flow of steam from the steam turbine to the heat transfer surface. The duct may include expansion joints, bypass spargers, drain pots, branch systems, and isolation valves. It is typically supplied and tested as part of the ACC.

steam turbine bypass: a condition of the unit operation in which some of the steam generated is discharged directly to the ACC, without passing through the steam turbine.

systematic error: the true systematic or fixed error, which characterizes every member of any set of measurements from the population. It is the constant component of the total measurement error (delta). It is sometimes called *bias.*

systematic uncertainty: an estimate of the ± limits of systematic error with a defined level of confidence (usually 95%).

terminal point: a specific location (such as a pipe joint or electric terminal block) at which a physical parameter (such as flow, pressure, or voltage) is of contractual significance.

test: a series of test runs.

test point: a specific location at which an instrument is installed.

test run: a complete set of data that permits analysis of capability per this Code. A test run typically lasts about 1 hr.

test tolerance: a commercial allowance for deviation from contract performance levels. Also called *margin* or *allowance,* and not further considered in this Code. See ASME PTC 1.

test uncertainty: the overall uncertainty in results due to the combined effects of instrument inaccuracy, transient conditions, and reading and methodological errors.

thermal performance: the capability of the ACC at operating conditions compared against established design criteria. Fan power or other ancillary factors may be included.

turbine exhaust: the exhaust connection of the steam turbine. It may be a flange or a landing bar for a weld. The turbine exhaust is typically not supplied with the ACC but forms the inlet steam flow boundary of the ACC test. See also *condenser pressure*.

uncertainty (U_{95}): an estimate of the limit of the error of a test result; the interval about the measurement or result that contains the true value for a given confidence level.

unit: a system comprising one or more boilers or heat-recovery steam generators (HRSGs), one steam turbine and the ACC serving it; may also refer to the ACC alone.

vacuum system: see *air-removal system*.

variation: in a test parameter, the slope of the linear least square fit of the parameter versus time multiplied by the time period of the test run.

wind wall: the vertical perimeter walls above the fan deck.

Section 3
Guiding Principles

3-1 INTRODUCTION

The objective of this Section is to provide guidance for testing of air-cooled steam condensers (ACC) and to outline the overall considerations, agreements, plans, limitations, requirements and evaluation of a complete test. The subsections in Section 3, Guiding Principles specifically describe the following:

(a) agreements of the parties
(b) test facilities to be incorporated during design and before test
(c) general arrangement of the test equipment
(d) starting and duration of tests
(e) test personnel
(f) operation during test
(g) preliminary tests
(h) conduct of the test
(i) test limitations
(j) outline of pretest and post-test uncertainty analysis
(k) criteria of inconsistent test results
(l) comparison of test results

It is important to structure a site-specific test plan for the testing that is to take place and to have designed the equipment with facilities and hardware needed to support required test instrumentation. The test plan should follow the guidelines and recommendations given in Section 3. In this manner, inconsistencies associated with the test execution, communications, procedure adherence, and test schedule can be greatly diminished. The ACC acceptance test can be conducted with other tests, provided the limitations in subsection 3-8 are met.

Before proceeding to select, construct, install, calibrate or operate instruments, relevant sections of ASME PTC 19, Series of Supplements on Instruments and Apparatus, should be reviewed for detailed instructions.

In contrast to many other types of equipment, during typical operation, an ACC's performance is likely diminished in moderate wind conditions typically due to interference effects from the nearby structures, fan inlet air flow separation, recirculation effects, interference, and maldistribution of the air in the plenum. These effects on ACC performance may not be captured by a Code test but should instead be considered in the design or taken into account as a reduced performance expectation, as discussed in Nonmandatory Appendix K.

The importance of conducting Code tests under stable operating and weather conditions cannot be overemphasized. Unstable conditions can disqualify a test, as defined in para. 3-8.3.2.

If the ACC to be tested is part of a multiple-unit complex, it is recommended that all the units be tested simultaneously. As a minimum, all of the operable fans of adjacent ACC units should be in operation during the test.

Normal cogeneration steam loads shall be allowed during the test. However, steam turbine bypass operation shall not be allowed.

3-2 AGREEMENT AMONG PARTIES TO THE TEST

For multiparty tests, agreement shall be reached on the specific objectives of the test and on establishing the method of operation. The agreement shall reflect the intent of any applicable contract or specification. Any specified or contract operating conditions, or any specified performance that are pertinent to the objective of the test shall be ascertained. Any omissions or ambiguities as to any of the conditions are to be eliminated or their values or intent agreed upon before the test is started. The cycle arrangement and operating conditions shall be established during the agreement on test methods.

3-2.1 Contractual Agreements

The following is a list of typical issues for which agreement shall be reached in the contractual specification with the ACC supplier. These are concepts that must be addressed prior to the construction of the ACC, as they will impact the test philosophy and method.

(a) objective of the test (e.g., thermal capability, deviation from design condenser pressure, deviation from design steam flow)
(b) test boundaries, especially if they differ from scope boundaries
(c) the intent of any contract or specification limiting the timing of the test, operating conditions, and guarantees, including definitions
(d) treatment of anticipated deviations from the requirements of this Code
(e) means of determining or estimating steam enthalpy
(f) means for determining condensate flow rate and associated uncertainty

Table 3-2.2 Noncondensible Gas Load Limits

SI Units		U.S. Customary Units	
Total Exhaust Steam Flow to ACC, kg/sec	Noncondensible Gas Load Limit Standard, m^3/hr	Total Exhaust Steam Flow to ACC, lb/hr	Noncondensible Gas Load Limit, scfm
Up to 15	4.0	Up to 100,000	2.0
15–30	8.0	100,000–250,000	4.0
30–60	9.0	250,000–500,000	5.0
60–125	10.0	500,000–1,000,000	6.0
125–250	13.0	1,000,000–2,000,000	7.5
250–375	16.0	2,000,000–3,000,000	9.0

(g) procedure for determining the condition of the ACC's external surfaces prior to the test per paras. 3-4.1 and 3-4.2

(h) action to be taken on evidence that the condition of the ACC is unsuitable for testing

(i) method and data for initial pretest uncertainty analysis and post-test uncertainty analysis calculation

(j) provisions for temporary installation of test instruments (see also Section 4)

3-2.2 Pretest Agreements

The following is a list of typical items upon which agreement shall be reached prior to conducting the test and incorporated into the site-specific test plan:

(a) measurements to be used in the calculation of test variables.

(b) means for maintaining constant or controllable test conditions.

(c) number, location, type, and calibration of instruments.

(d) valve lineup defining the position of applicable manual and automatic valves and operation of the air removal system.

(e) means for verification that allowable noncondensibles are within limits of Table 3-2.2.

(f) operation of the fans, including means for measuring fan power and correction methodology for line losses between location of measurement and the guarantee location.

(g) method for confirming condensate chemistry (e.g., plant instrumentation, external lab test).

(h) organization and training of test participants, test direction, arrangements for data collection, and data reduction.

(i) operating conditions during test runs including, but not limited to, the electrical output loads, extraction levels, and cycle makeup.

(j) allowable deviations from design, test code, or test plan.

(k) number of test runs.

(l) duration of each test run.

(m) duration of stabilization period prior to beginning a test run.

(n) methods for determining the validity of repeated test runs.

(o) frequency of observations.

(p) analytical correction procedures and factors to correct test conditions within para. 3-8.3 limits to specified conditions.

(q) method of conducting test runs to determine the value of any correction factors that cannot be analytically determined.

(r) system limitations caused by external factors that prevent attainment of design operation within a practical time period. This may include a situation where full electrical load cannot be attained or a case where a steam host is unavailable to accept process steam.

(s) method of determining corrected test results.

(t) specific responsibilities of each party to the test.

(u) test report distribution.

(v) pretest uncertainty analysis.

(w) acceptance criteria for cleanliness of heat transfer surfaces.

3-3 UNCERTAINTY ANALYSIS

Test uncertainty is an estimate of the magnitude of the error of the test result. Test uncertainty and test tolerance are not interchangeable terms. This Code does not address test tolerance, margin, or allowance since these are commercial terms.

Procedures relating to test uncertainty are based on concepts and methods described in ASME PTC 19.1, Test Uncertainty. ASME PTC 19.1 specifies procedures for evaluating measurement uncertainties from both random and systematic errors, and the effects of these errors on the uncertainty of a test result. This Code addresses test uncertainty in the following four sections:

(a) Section 1 defines the maximum test uncertainties.

(b) Section 3 defines the requirements for pretest and post-test uncertainty analyses, and how they are used in the test.

(c) Section 5 and Nonmandatory Appendix C provide guidance for conducting pretest and post-test uncertainty analyses.

3-3.1 Pretest Uncertainty Analysis

A pretest uncertainty analysis shall be performed to determine if the test has been designed to meet Code requirements. Estimates of systematic and random error for each of the proposed test measurements shall be used to help determine the number and quality of test instruments required for compliance with Code or contract specifications. In addition, a pretest uncertainty analysis can be used to determine the correction factors, which are significant to the corrected test results. Finally, a pretest uncertainty analysis shall be used to determine the level of accuracy required for each measurement to maintain overall Code objectives for the test.

3-3.2 Post-Test Uncertainty Analysis

A post-test uncertainty analysis shall be performed to determine if the test has met Code requirements.

3-4 TEST PREPARATIONS

3-4.1 Equipment Inspection

All parties shall have a reasonable opportunity to inspect the ACC and its allied equipment. Prior to the test the equipment shall be examined, and the conditions shall be as follows:

(a) The fans shall be in good working order with fans rotating in the correct direction at the correct speed and blade pitch so that the average fan motor power is within ±10% of the design motor power at the design thermal conditions.

(b) The external heat transfer surfaces shall be essentially free of foreign material and debris that might impede airflow or adversely affect the heat transfer. If cleaning of the surfaces is necessary, it shall be performed by a commercially acceptable method.

(c) In the event that the equipment is not in satisfactory operating condition, no adjustments shall be made that are not practical for long-term commercial operation.

(d) The noncondensibles shall be limited to the values shown in Table 3-2.2.

(e) The noise abatement equipment, as applicable, shall be in place.

3-4.2 Instrument Calibrations

All pressure measuring devices, temperature sensors, and electric power meter test instrumentation shall be calibrated against reference standards traceable to National Institute of Standards and Technology (NIST) or recognized physical constants. Note that where this Code refers to NIST standards and calibrations, other nations' equivalent standards laboratories may be used as appropriate for the locale of the testing.

Test variables of a secondary nature, such as wind speed and direction devices, need not be calibrated against a reference standard, but may instead be calibrated against other calibrated instruments or transfer standards or can be checked in place with two or more instruments at the same location measuring the same variable.

Instruments shall have been calibrated and inspected in accordance with accepted engineering practice. Instrument calibration shall be conducted in advance of the test. Specifically, pressure, temperature, and condensate flow sensors shall be calibrated within six months prior to the test; electric meters and wind speed and direction devices shall be annually calibrated. Before testing, but after the on-site wiring connections are made, there shall be sufficient comparisons of all similar temperature sensors to ensure their relative accuracy.

At the request and cost of the requesting party, a post-test calibration may be performed. If an instrument is found to be out of calibration, then its influence on the test shall be evaluated.

There shall be a written procedure for the calibration of each type of instrument. Records indicating the most recent calibration of each instrument shall be made available upon request. Calibrations should encompass the expected measurement range and be comprised of at least two points more than the order of any calibration curve fit. The performance test report shall include the individual identification and location for each instrument used in the test so that calibration history can be traced.

The ASME PTC 19, Series of Supplements on Instruments and Apparatus can be used as a guide to the selection use and calibration of the measurement instruments.

3-5 ARRANGEMENT OF TEST APPARATUS

(a) The performance test shall be conducted with all components of the ACC configured as specified for normal operation. Any changes from normal operation or configuration shall be agreed prior to the test.

(b) Boundaries of the test shall be defined as encompassing sufficient parameters to determine performance of the ACC. See Fig. 3-5 for a typical test set-up or the boundary of supply of the ACC manufacturer.

(1) steam supply to the ACC at the upstream side of the turbine exhaust expansion joint or terminal point of ACC supplier's scope of supply

(2) power at the fan motor terminals — mutually agreed to correction can be applied if measurements are taken at a more convenient location

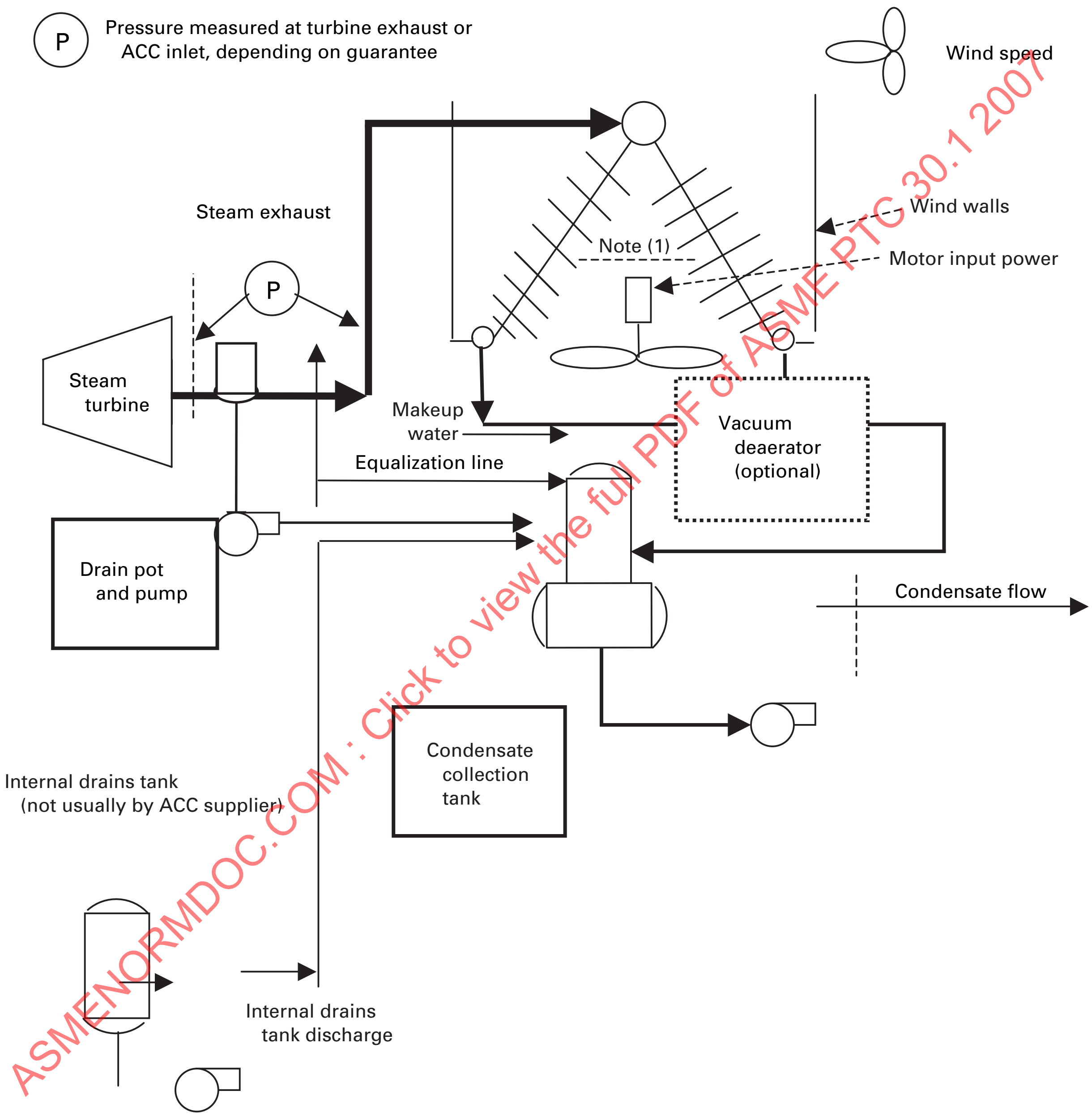
(3) makeup water at the inlet to the deaerator

3-5.1 Required Measurements

The following parameters need to be determined for a valid test. Additions or deletions may be necessary for a specific test arrangement.

(a) inlet air temperature

Fig. 3-5 Arrangement of Test Apparatus



NOTE:
(1) Air temperature measured at discharge of fan.

(b) wind speed — measured at an unobstructed location
(c) fan power
(d) condensate flow — downstream of the condensate pumps at a location fulfilling the requirements of ASME PTC 19.5
(e) steam quality — not measured directly
(f) makeup water flow
(g) makeup water temperature
(h) condenser pressure at boundary limit
(i) condensate temperature
(j) barometric pressure
(k) O_2 concentration at the outlet of the condensate tank, if there is a dissolved oxygen guarantee

3-6 TEST PERSONNEL

Test personnel shall be familiar with the Code, their assigned role, the test parameters involved, and all the test boundary limitations. All test parties shall have a clear understanding of the test object, the proposed procedures, and the results to be obtained. Through prior discussion or prior agreement, one person or a team consisting of one person from each test party shall be responsible for the test, operational coordination, calculations, and test results. If necessary, the responsible person(s) shall have the authority to modify aspects of the test and/or the plant operation.

3-7 METHOD OF OPERATION DURING THE TEST

Operation of the plant during the test shall depend on the objective of the test. Only steady-state operation within the limitations of the Code as delineated in subsection 3-8 will be permitted. The operating cycle shall be isolated to the maximum extent practical.

3-8 CONDUCT OF TEST

This subsection provides guidelines on the actual conduct of the performance test and addresses the following areas:
(a) recommended test modes (para. 3-8.1)
(b) starting and stopping tests and test runs (para. 3-8.2)
(c) testing conditions (para. 3-8.3)
(d) adjustments prior to and during tests (para. 3-8.4)
(e) duration of test runs, number of test runs, and frequency of readings (para. 3-8.5)

3-8.1 Test Modes

The ACC shall be operated in a manner consistent with the controlling guarantee case. For example, if the guarantee case is based on a turbine valves wide-open (VWO) condition with a prescribed extraction flow, then testing should take place at that condition.

The *controlling guarantee case* is that combination of thermal duty, condensing pressure, fan operation, and inlet air temperature, which dictates the design of the ACC. It is often called the design case, and is usually the one guarantee case. If, however, there is more than one guarantee case, the most stringent of these will be the controlling guarantee case, and the vendor shall identify it.

The ACC performance curves shall show the controlling guarantee case and shall indicate the performance required for that case. For any other guarantee case, the performance curves are expected to show that the ACC performance is equal to or better than the requirements of the case.

The purpose of the performance test is to show that the ACC will meet the performance required at the controlling guarantee case. It is inherent in the ACC performance curves that if the performance at the design case is met then performance at the less stringent cases will also be met. Therefore, multiple test cases are not required even if there is more than one guarantee case.

3-8.2 Starting and Stopping Tests and Test Runs

The test coordinator is responsible for ensuring that all data collection begins at the start of the test and continues for the full duration of the test.

3-8.2.1 Starting Criteria. Prior to starting each performance test, the following conditions must be satisfied:
(a) Operation, configuration, and disposition for testing have been reached in accordance with test requirements, including
(1) equipment operation and method of control
(2) turbine configuration and extraction conditions
(3) valve line-up and auxiliary equipment status
(4) ACC operation meets the allowable deviations of para. 3-8.3.2
(5) freeze protection not in effect
(6) air removal equipment operating at 100% as specified
(b) *Stabilization.* Prior to starting the test, the plant must be operated for a sufficient period of time at test load to demonstrate and verify stability in accordance with para. 3-8.3 criteria.
(c) *Data Collection.* Data acquisition systems are functioning, and test personnel are in place and ready to collect samples or record data.

3-8.2.2 Stopping Criteria. Tests are normally stopped when the test coordinator is satisfied that requirements for a complete test run or series of runs have been achieved. The test coordinator should verify that the methods of operation during testing, as specified in para. 3-8.3, have been met. The test coordinator may extend or terminate the test if the requirements are not met or it is apparent that test requirements will not be met.

Data logging should be checked to ensure completeness and quality, prior to stopping the test.

3-8.3 Testing Conditions

3-8.3.1 Test Stabilization. Preparatory to any test run, the steam turbine, ACC, and all associated equipment shall be operated for a sufficient time to attain steady-state condition. Steady-state conditions shall be obtained when the criteria of paras. 3-8.3.2 and 3-8.3.3 have been met.

3-8.3.2 Operating Conditions. Every effort shall be made to conduct each test run under specified operating conditions, or as close to specified operating conditions as possible in order to minimize the magnitude of correction factors. This paragraph provides guidelines on the allowable deviations in operating conditions from the reference condition. Operating conditions must be as constant as practical before the test run begins and shall be maintained throughout the test run in order to minimize the associated random uncertainty. Tests may be conducted in light rain, sleet, or snow, provided that the variation in test parameters are stable and the test conditions conform to the following limitations. Under no circumstances shall a test be performed in conditions that jeopardize the safety of personnel. Steam turbine controls shall be fine-tuned prior to the test run to minimize fluctuations.

(a) Variation in a test parameter is defined as the slope of the linear least square fit of the parameter versus time multiplied by the time period of the test run. Variation of the instantaneous test reading about the mean is not a valid criterion for rejection of a test run. For a valid test run, variations in test conditions shall be within the following limits:

(1) Condensate mass flow shall not vary by more than 2% during the test run.

(2) Inlet dry-bulb temperature shall not vary by more than 3.0°C (5.4°F).

(3) The initial temperature difference (ITD) is the difference between the saturated steam temperature at the condenser pressure and the inlet air temperature. The ITD shall not vary by more than 5% during the test run to verify stable conditions.

(4) The wind velocity shall be measured in accordance with para. 4-3.7 of this test procedure and shall not exceed the following:

(a) Average wind velocity shall be less than or equal to 5.0 m/s (11.1 mph).

(b) One-minute duration velocity shall be less than 7.0 m/s (15.6 mph).

(b) The following deviation from design conditions shall not be exceeded at any time during the test run:

(1) dry-bulb temperature: ±10°C from design (18°F) but greater than 5°C (41°F).

(2) condensate mass flow: ±10% of the design value

(3) total fan motor input power: ±10% of the design value after air density correction.

(4) the makeup water flow rate shall be stable and ≤ 100% of the design values

3-8.3.3 ACC Operation. The ACC shall be in normal operation during the test run. No special adjustments shall be made to the ACC that are inappropriate for normal and continuous operation.

3-8.4 Adjustments Prior to and During Tests

This paragraph describes the following three types of adjustments related to the test:

(a) permissible adjustments during stabilization periods or between test runs

(b) permissible adjustments during test runs

(c) nonpermissible adjustments

3-8.4.1 Permissible Adjustments During Stabilization Periods or Between Test Runs. Acceptable adjustments prior to the test may be made to the equipment and/or operating conditions within manufacturer's recommended operating guidelines. Stability may need to be established following any adjustment. Typical adjustments prior to tests are those required to correct malfunctioning controls or instrumentation or to optimize plant performance for current operating conditions. Suspected instrumentation or measurement loops may be recalibrated. Adjustments to avoid corrections or to minimize the magnitude of performance corrections are permissible (e.g., adjustment of an extraction flow).

3-8.4.2 Permissible Adjustments During Test Runs. Permissible adjustments during test runs are those required to correct malfunctioning controls, maintain equipment in safe operation, or to maintain plant stability. Adjustments are only permitted provided that the deviation and stability criteria of para. 3-8.3.2 are met. Switching from automatic to manual control and adjusting operating limits or set points of instruments or equipment should be avoided during a test run.

3-8.4.3 Nonpermissible Adjustments. Any adjustments that would result in equipment being operated beyond manufacturer's operating, design, or safety limits and/or specified operating limits are not permitted. Adjustments or recalibrations that would adversely affect the stability of a primary measurement during a test are not permitted.

3-8.5 Duration of Runs, Number of Test Runs, and Number of Readings

A test run is a complete set of observations with the ACC at a stable operating condition. A test is the average of a series of test runs.

3-8.5.1 Duration of Test Runs. Each run shall continue for a period sufficiently long to ensure accurate and consistent results as determined by uncertainty analysis. Generally a duration of 1 hr is sufficient to ensure collection of a valid data set.

3-8.5.2 Number of Test Runs. The minimum number of test runs is six, conducted over at least 2 days. Several test runs, however, may be made in sequence. The recommended number of test runs provides a sufficient number of test results for a statistically significant evaluation of uncertainty. The duration of 2 days ensures that a sufficient variation of uncontrolled conditions, such as wind speed and direction, within the limits of the Code are encountered. This will permit a reasonable inference to random and spatial uncertainties.

3-8.5.3 Number of Readings. Variables should be recorded at the following minimum frequencies:

(a) condensate flow measurements: once per minute.

(b) fan motor power measurements (kW, or volts, amps, and power factor): one at the beginning and one at the end of the test.

(c) ACC pressure and temperature measurements: 1 min intervals throughout the period of the test run.

(d) barometric pressure: at the end of each test run.

(e) air inlet temperatures: 1 min intervals throughout the period of the test run.

3-8.5.4 Preliminary Test Runs. Preliminary test runs, with records, serve to determine if equipment is in suitable condition to test, to check instruments and methods of measurement, to check adequacy of organization and procedures, and to train personnel. All parties to the test may conduct reasonable preliminary test runs as necessary. Observations during preliminary test runs should be carried through to the calculation of results as an overall check of procedure, layout, and organization. If such preliminary test run complies with all the necessary requirements of the appropriate test code, it may be used as an official test run within the meaning of this Code.

Section 4
Instruments and Methods of Measurement

4-1 INTRODUCTION

This section describes the instruments and the methods for their application that are required for the performance test described in this Code. While reference may be made to existing standards and procedures, major requirements and considerations, which are of particular relevance to ACC performance testing, are summarized where appropriate. Not all instruments or techniques described in this section are applicable to every ACC test program. Consult the guiding principles, particularly para. 3-5.1 to determine the required measurements.

Where this Code refers to National Institute of Standards and Technology (NIST) standards and calibrations, those of other equivalent national standards laboratories may be used as appropriate for the locale of the testing.

Before proceeding to select, construct, install, calibrate, or operate instruments, relevant sections of the ASME PTC 19 Series of supplements on Instruments and Apparatus, such as ASME PTC 19.3, Temperature Measurement, and ASME PTC 19.5, Flow Measurement, should be consulted for detailed instructions. The use of a data acquisition system is recommended. The parties to the test shall agree to the sampling rates and compression settings such that the collected data meet the requirements of the Code.

Achievement of the required accuracy for each measured parameter is the single most important criterion in selection of an appropriate method of measurement. This Code shall not be construed as preventing the use of advanced technologies or methods of measurement not described herein, provided that the uncertainty requirements of subsection 1-3 are achieved.

It is highly recommended that provisions for ACC performance testing be incorporated into the design of the facility where the ACC is located. Backfitting an existing system for the required measurements can be very expensive and time-consuming at best, and virtually impossible at worst.

4-2 MEASUREMENT OF ENVIRONMENTAL EFFECTS

Prior to the test, the parties to the test shall jointly conduct a survey of the area surrounding the ACC. All unspecified and/or unanticipated conditions that may contribute to variations in ACC performance, such as heat sources, nearby buildings, or structures that may affect fan performance shall be investigated. Methods necessary to quantify the effects on test results shall be determined by mutual agreement. For additional details, see Nonmandatory Appendix K.

It is not the intent of the Code to specify the methods to determine the effects of unspecified and/or unanticipated conditions, but rather to make the parties aware that test results may be affected by factors that are beyond the scope of the Code.

4-3 LOCATION OF TEST POINTS

4-3.1 General

Figure 3-5 illustrates the general location of the test points. Additional test points not required by this Code may be included for reference purposes by mutual agreement between the parties to the test.

Internal test points, such as basket tips and thermowells, should be located to avoid interference with internal steam duct structure, bracing, turning vanes, etc. The exact locations, however, shall be determined by mutual agreement, as may be required by equipment arrangement.

4-3.2 Condenser Pressure

Test points in the steam turbine exhaust duct are required to obtain steam pressure data for the ACC.

To provide an overall averaged measurement, there shall be at least four measurement points per turbine exhaust. These points shall be symmetrically distributed about the perimeter of the steam turbine exhaust duct as near the flange of the steam turbine exhaust or pressure guarantee location as possible. The mutually agreed location of these measurement points shall not be in the wake of structural members that may result in inaccurate measurements.

4-3.3 Steam Temperature

In order to provide confirmation of the saturated steam condition, steam temperature measurements shall be taken. A single test point located in the area of the condenser pressure measurement test points is sufficient.

4-3.4 Steam Quality

Steam quality and enthalpy are not measured values. They shall be determined by methods described in para. 4-4.3.

4-3.5 Atmospheric Pressure

As atmospheric pressure is generally uniform at a given elevation, a single atmospheric pressure measurement point near ground level at the test site is sufficient.

4-3.6 Inlet Air Temperature

The inlet air temperature measurement shall consist of a specified number of dry-bulb temperature sensors.

At least one inlet dry-bulb temperature measuring point per fan shall be selected, with a minimum of 12 total inlet dry-bulb temperature-measuring points per unit.

The measurement points shall be located downstream from the fan discharge plane, within the air stream, as near to the fan deck elevation as practical. The walkway or fan bridge is a suggested location.

At least one inlet dry-bulb temperature measuring point per fan shall be selected, with a minimum of 12 total inlet dry-bulb temperature-measuring points per unit. Measurement points shall be generally in the outer half of the fan radius, on the side nearest to the closest ACC perimeter wall and 1 m from the outer fan diameter.

An alternative arrangement is to locate the temperature instruments around the perimeter of the ACC. These instruments shall be separated in equal amounts and positioned equidistantly around the ACC perimeter with one in the center of the ACC plot. These instruments shall be hung 1 m below the top of the air inlet opening.

If these locations are not accessible, due to the design of the ACC, then other locations shall be selected and agreed upon.

For informational and diagnostic purposes, without any implied bearing or impact to the test and its results, ambient air dry-bulb temperature measurements may be taken. The involved parties shall mutually agree on the location of this measurement point.

4-3.7 Wind Velocity

Thermal performance of an ACC is affected by ambient wind velocity. Increased wind speed may lead to a reduction of ACC airflow and reduced ACC performance. Furthermore, high wind velocities can lead to warm air recirculation, causing an additional degradation of ACC performance. In consideration of these effects, ambient wind velocity shall be measured.

To gain reliable ambient wind velocity, the wind velocity shall be measured at least 5 m above grade at a location within the plant without interference from other equipment, buildings, structures, and topography. The measured wind velocity at this location shall be extrapolated to the top of the ACC utilizing the following correlation:

$$V_{\text{top of ACC}} = V_{\text{measurement}} \cdot \left(\frac{Z_{\text{top of ACC}}}{Z_{\text{measurement}}}\right)^{0.2}$$

4-3.8 Condensate Flow

Since the measurement of steam flow is impractical and inaccurate, measurement of condensate flow and makeup flow shall be made.

Measurement of the flow shall be taken in the condensate forwarding pump discharge piping in accordance with ASME PTC 19.5. The measurement location should be downstream of the condensate pump recirculation piping and upstream of any branches. If not possible, then condensate pump recirculation flow and branch flows must be isolated or measured.

Measurement of the makeup water flow shall be taken by any convenient means in accordance with ASME PTC 19.5.

At a minimum, 20 pipe diameters of undisturbed, straight pipe length upstream and four pipe diameters downstream of the flow measurement device shall be provided. If this is not practical, an alternate location in accordance with ASME PTC 19.5 shall be selected by mutual agreement.

Steam flow to the ACC shall be calculated by a mass balance around the condensate tank with consideration of any inlet flows (including any makeup flow) upstream of the measurement point and the change in level of the tank during test. Design values may be used for those flow streams representing less than 3% of the design ACC steam flow.

4-3.9 Condensate and Makeup Temperatures

Condensate temperature shall be measured in the condensate tank. A thermowell should be located to provide an overall average mixed temperature of the condensate. As internal access is typically impractical after installation of the ACC, an internal test connection should be specified during the ACC design.

Makeup water temperature shall be measured. A thermowell should be suitably located to accurately measure this temperature.

4-3.10 Fan Motor Input Power

ACC fan power guarantees refer to the power required at the motor input terminals or other clearly defined guarantee locations. For practical and safety reasons, fan power is typically measured at the output of the motor control center (MCC). For other power distribution schemes, best efforts shall be made to select a measurement location to minimize corrections between the location of power measurement and the location of power guarantee. The selected location shall allow for the quantification of other loads, if any, such that the input fan motor input power can be obtained. Measurement of multiple fan motor loads on a common bus is acceptable.

4-3.11 Condensate Oxygen Concentration

Accurate measurements of dissolved oxygen from a subatmospheric vessel are not obtained easily. If

Fig. 4-4.1-1 Basket Tip

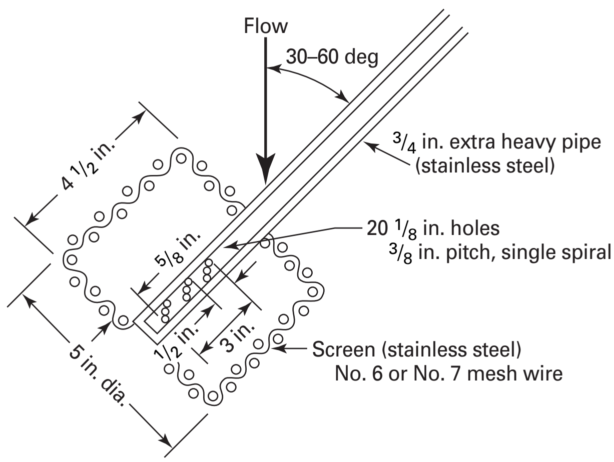
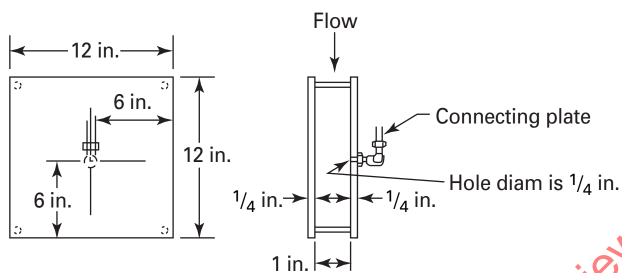


Fig. 4-4.1-2 Guide Plate



required, dissolved oxygen shall be measured in accordance with Nonmandatory Appendix F.

4-4 INSTRUMENTATION AND METHODS OF MEASUREMENT

4-4.1 Condenser Pressure

Basket tips or guide plates shall be located in the interior of the steam duct according to para. 4-3.2. The basket tips shall be constructed as shown in Fig. 4-4.1-1 and shall be installed at an angle between 30 deg and 60 deg to the mean flow direction. Alternatively guide plates shall be constructed as shown in Fig. 4-4.1-2 and shall be oriented so that the steam flow is parallel to the guide plates. Velocities in the steam duct are extremely high and may be turbulent. If required, the basket tips shall be sufficiently braced in several directions.

Pressure-sensing piping for the pressure measurement shall conform to the general requirements of ASME PTC 19.2. Particular care shall be taken to ensure that all piping and connections are leak-free. Piping shall be routed by the most direct practical manner. It shall be pitched continuously upward from the primary sensing element to the pressure measurement device. Air bleeds shall be incorporated to allow for purging of any condensate from the piping. Air bleeds, if required, shall not be continuous, but only intermittent. Each pressure measurement point shall be provided with a dedicated pressure measurement device. Manifolds shall not be used.

Pressure measurements shall be made with instruments having an accuracy of at least ±0.035 in. HgA to ensure a concrete uncertainty target that is achievable and at the same time provides a good test.

Absolute pressure transducers are required. Transducers shall be calibrated before the test program using NIST-traceable standards in accordance with the general procedures given in ASME PTC 19.2.

4-4.2 Steam Temperature

ASME PTC 19.3 shall be used to stipulate instrumentation, details of construction of thermowells, and reading of instruments.

Temperature measurements shall be made with instruments having an accuracy of at least ±0.1°C (±0.2°F). All temperature measuring devices shall be calibrated using NIST-traceable standards following the general procedures given in ASME PTC 19.3. Four-wire resistance temperature detectors (RTDs) shall be used. A minimum of five calibration points covering the expected range of temperatures shall be taken.

4-4.3 Steam Quality

Steam quality and enthalpy are not measured values. They shall be determined by analytical methods such as heat/mass balance around the steam turbine, cycle modeling, or analytical method (turbine expansion line) as in Nonmandatory Appendix E.

4-4.4 Atmospheric Pressure

Atmospheric pressure shall be measured utilizing an electronic barometer, or other suitable device, with an accuracy of at least ±0.4 kPa (0.1 in. HgA).

4-4.5 Inlet Air Temperature

Temperature measurements shall be made with instruments having an accuracy of at least ±0.1°C (±0.2°F). All temperature measuring devices shall be calibrated using NIST-traceable standards following the general procedures given in ASME PTC 19.3. Four-wire RTDs shall be used. A minimum of five calibration points covering the expected range of temperatures shall be taken.

4-4.6 Wind

Wind speed shall be measured with a meteorological type rotating cup or propeller type anemometer with preferably a continuous remote readout and recording capability and an accuracy of at least ± 0.04 m/s (± 0.1 mi/hr). Wind direction shall be measured by a vane-type device, which may be integral to the anemometer.

4-4.7 Condensate Mass Flow

As measurement of ACC steam flow is impractical, it shall be derived from a mass balance around the condensate tank to determine ACC condensate flow into the condensate tank. The mass balance should consider condensate pump discharge flow, ancillary drains, make-up water, condensate pump recirculation, other flows, and tank inventory change, as applicable.

To the extent possible, ancillary system drains flowing into the condensate tank or other parts of the ACC during the test shall be closed. In the event that drains cannot be closed, then the mass flow of the drains shall be determined by ancillary measurement, heat/mass balance or by other mutually agreed methods.

The level of the condensate in the condensate tank shall be continuously measured during the test period in order to determine change of condensate mass. Change in level may be measured by level gauges or level transmitters.

The recommended uncertainty limit of the main condensate flow measurement device is 1% of the total condensate flow through the test measurement device. Instrument selection and details of measurement techniques shall be in accordance with ASME PTC 19.5. Satisfactory instruments include venturi meters, orifice meters, and flow nozzles.

Alternatively an ultrasonic flow meter may be utilized. If so it 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. Readings shall be taken at six positions 30 deg 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%, the cause shall be investigated. Use of an ultrasonic flow meter will likely result in a greater uncertainty for the condensate flow measurement as compared to an inline flow element.

Otherwise, in rare instances, flow rates may be determined by plant heat balance method, provided the uncertainty does not exceed 2%.

4-4.8 Condensate and Makeup Temperatures

The condensate temperature shall be measured in the condensate tank. When this is not possible, temperatures may be measured downstream of the condensate pump. In that case the temperature shall be adjusted for the pump work. Ideally, makeup water and ancillary flows into the condensate tank should be isolated. If isolation is not possible, then adjustment of the measured temperature utilizing energy balance with either measurement or estimate of the flow and temperature shall be required.

For both the condensate and makeup temperatures, ASME PTC 19.3 shall be used to stipulate instrumentation, details of construction of thermowells and the reading of instruments.

Temperature measurements shall be made with instruments having an accuracy of at least ±0.1°C (±0.2°F). All temperature measuring devices shall be calibrated using NIST-traceable standards following the general procedures given in ASME PTC 19.3. Four-wire RTDs shall be used. A minimum of five calibration points covering the expected range of temperatures shall be taken.

4-4.9 Fan Motor Input Power

Fan motor input power shall be determined by direct measurement of motor kilowatt input or by measurement of the voltage, current and power factor as per ASME PTC 19.6, Electrical Power Measurement. Acceptable instruments for determining power, in preferred order, are

(a) wattmeter

(b) voltage, current, power factor meters

For variable frequency drive (VFD) applications, suitable measuring devices shall be used.

If measurements are not made at the guarantee location, corrections to the guarantee power location shall be made by measurement of voltage drop or by computation of loss between the two locations. See Nonmandatory Appendix L as an example of line loss calculation. The method and results of this correction shall be mutually agreed between the parties and taken into account in the fan motor input power measurement.

4-4.10 Condensate Oxygen Concentration

Accurate measurements of dissolved oxygen from a subatmospheric vessel are not obtained easily. If required, dissolved oxygen shall be measured in accordance with Nonmandatory Appendix F.

Section 5
Computation of Results

5-1 GENERAL

This section covers the reduction of the test data, computation of test results, adjustment of results to guarantee conditions, and interpretation of adjusted results by comparing them to the guarantee conditions. The basic procedure for computation of performance capability is as follows:

(a) Review the raw test data and select the readings on the basis of the requirements of Sections 3 and 4.

(b) Average the selected test data.

(c) Compute the design value of the logarithmic mean temperature difference (LMTD).

(d) Compute value of number of transfer units (NTU) at the design point.

(e) Compute the value of gamma (Γ) at the design points.

(f) Adjust the steam quality, atmospheric pressure, fan power, condenser pressure, condensate temperature, and inlet air temperature to guarantee conditions.

(g) Compute the capability of the unit at guarantee conditions.

Details of required computation are included in subsection 5-5.

5-2 REVIEW OF TEST DATA AND TEST CONDITIONS

The raw test data shall be carefully reviewed to ensure data selection will accurately represent the ACC performance. Data review should start at the beginning of the test, providing an opportunity for immediate discovery of possible errors in instruments, procedures, or measurement methods. Guidance for the review of data and test conditions is provided in Sections 3 and 4. Significant deviations shall be corrected during the preliminary test run if practicable. Any uncorrected or uncontrollable conditions that violate the provisions of Sections 3 and 4 shall be described in the test report. At the end of the test period, but prior to the removal of the test instrumentation, a final review of the data shall be made to determine whether or not an immediate repeat test is necessary. This review will also assist in the establishment of the reliability of the test. The review shall include a post-test uncertainty analysis for evaluation of deviations from ideal of the following, and the effects of these deviations on the test results:

(a) comparison of test and design conditions

(b) test site environment, including atmospheric conditions

(c) air in-leakage

(d) steady-state conditions

(e) measurement uncertainty

5-3 REDUCTION OF TEST DATA

The purpose of averaging the raw test data is to provide a single set of data that is representative of all the collected data. This averaged data shall be used in calculations to determine thermal performance. Multiple readings taken over time and/or readings of the same quantity by multiple instruments at a given station shall be arithmetically averaged.

5-3.1 Air-Side Conditions Data Reduction

(a) Inlet Air Temperature. Inlet air temperature data shall be averaged for each test run. Variations in inlet air temperature are normally small enough to allow arithmetical averaging of the temperatures.

(b) Atmospheric Pressure. The readings taken at the beginning and end of the test period shall be arithmetically averaged.

5-3.2 Steam Side Data Reduction

(a) Condenser Pressure. Condenser pressure measurements will be arithmetically averaged.

(b) Steam Flow Rate. Steam flow rate shall be determined by a mass and heat balance around the condensate tank and shall be arithmetically averaged.

5-4 ACC DESIGN DATA

In order to perform the calculations described in this subsection, the following design data must be provided by the ACC supplier. An example of an acceptable data sheet is in Nonmandatory Appendix G.

(a) atmospheric pressure, if required

(b) inlet air temperature

(c) exit air temperature

(d) volumetric air flow

(e) total fan power (at the motor terminals)

(f) condenser pressure

(g) steam mass flow

(h) steam quality

(i) condensate temperature, with correction curve if required

(j) dissolved O_2 concentration
(k) heat exchange surface (total air-side area)
(l) heat transfer coefficient (based on air-side area)
(m) performance curves, see Nonmandatory Appendix B

The values of $m_k = 0.45$ and $n = 0.33$ will be used, unless other values are provided by the vendor. See Nonmandatory Appendix D.

5-5 PARTICULAR CALCULATIONS AT THE GUARANTEE POINT

In order to perform the necessary adjustments of the test data to the guarantee conditions, the following quantities must be calculated at the design point:

(a) logarithmic mean temperature difference, LMTD
(b) number of transfer units, NTU
(c) gamma factor, Γ

5-5.1 Computation of LMTD at Guarantee Conditions

$$LMTD = Q/(U \times A)$$

where

A = heat exchange surface area, m^2
$LMTD$ = log mean temperature difference, K
Q = heat duty, W
U = overall heat transfer coefficient, $W/m^2/K$

and

$$Q = \dot{m} \times x \times h_{fg}$$

where

h_{fg} = design value of the latent heat of vaporization, J/kg
$\dot{m}$ = design value of the steam mass flow rate, kg/s
x = design value of the steam quality

5-5.2 Computation of Number of Transfer Units (NTU)

$$NTU = (T_o - T_i)/LMTD$$

where

T_i = design value of the air inlet temperature
T_o = design value of the air outlet temperature

5-5.3 Computation of Gamma Factor

It is convenient to define a constant factor based on design information for carrying out the adjustment calculation:

$$\Gamma = NTU/(e^{NTU} - 1)$$

5-6 ADJUSTMENT OF TEST DATA TO GUARANTEE CONDITIONS

5-6.1 General

This subsection develops a method for evaluation of the performance of an ACC from test data based on performance curves provided by the manufacturer.

5-6.2 ACC Performance Curves

The manufacturer should submit performance curves consisting of ACC pressure as function of total steam flow rate between 80% and 120% of the design steam flow rate for a set of inlet air dry bulb temperatures between 5°C and the maximum specified inlet air dry bulb temperature. The performance curves shall depict operation with all fans running at full speed. The ACC performance curves shall be based on constant fan pitch and motor speed (constant volumetric air flow rate).

The manufacturer should also provide trend line equations that can be used in place of reading values off the curves during the performance test. The design conditions including steam mass flow rate, steam turbine backpressure, steam quality, fan motor input power, atmospheric pressure, and inlet air dry bulb temperature shall be printed on the curves.

5-6.3 Adjustment for Steam Quality

The correction factor for steam quality, f_x, is calculated by

$$f_x = \frac{x_T}{x_G}$$

where

x_G = steam quality at guarantee conditions, kg/kg (lbm/lbm)
x_T = steam quality at test conditions, kg/kg (lbm/lbm)

5-6.4 Adjustment of Atmospheric Pressure

The correction factor for atmospheric pressure, f_p, shall be calculated by the following (see also Nonmandatory Appendix D):

$$f_p = \left[\frac{p_T}{p_G}(1 - \Gamma) + \Gamma\left(\frac{p_T}{p_G}\right)^{m_k}\right]^{-1}$$

where

m_k = 0.45, unless otherwise specified by the manufacturer
p_G = design barometric pressure, kPa (psia)
p_T = test barometric pressure, kPa (psia)

5-6.5 Adjustment of Fan Power

The correction factor for fan power, f_{fp}, can be calculated by

$$f_{fp} = \left(\frac{W_T^c}{W_G}\right)^{\frac{-1}{3-n}}\left[(1-\Gamma) + \Gamma\left(\frac{W_T^c}{W_G}\right)^{\frac{m_k-1}{3-n}}\right]^{-1}$$

where

n = 0.33, unless otherwise specified
W_T^c = test fan motor input power corrected for inlet air conditions, kW
W_G = guarantee fan motor input power, kW

The corrected fan motor power can be calculated by

$$W_T^c = \left(\frac{\rho_G}{\rho_T}\right)W_T$$

where

W_T = observed fan motor input power, kW
ρ_G = density of inlet air at guarantee conditions, kg/m^3 (lbm/ft^3)
ρ_T = density of inlet air at test conditions, kg/m^3 (lbm/ft^3)

The fan motor input power shall be corrected for any line losses between the measurement point and the boundary of supply for the condenser manufacturer.

5-6.6 Adjustment of ACC Pressure and Inlet Air Temperature

The adjustment of ACC pressure and inlet air temperature is made using the ACC performance curves. Enter the performance curve at the measured ACC pressure and inlet air temperature to find a steam mass flow rate.

The correction factor, f_{pc}, can be calculated by

$$f_{pc} = \frac{\dot{m}_G}{\dot{m}_{pc}}$$

where

$\dot{m}_G$ = guarantee mass flow rate
$\dot{m}_{pc}$ = mass flow rate at measured turbine backpressure and inlet air temperature

5-6.7 Computation of Capability

The ACC capability will be calculated by

$$C = \frac{\dot{m}_{s,T}^c}{\dot{m}_{s,G}} \times 100$$

where

C = steam flow capability, %
$\dot{m}_{s,T}^c$ = test mass flow of steam, kg/s (lbm/hr) corrected for steam quality, ambient pressure, fan motor power, inlet air temperature, and turbine backpressure
$= f_x \times f_p \times f_{fp} \times f_{pc} \times \dot{m}_{s,T}$
$\dot{m}_{s,G}$ = guaranteed mass flow rate of steam, kg/s (lbm/hr)
$\dot{m}_{s,T}$ = test mass flow rate of steam, kg/s (lbm/hr)

5-6.8 Interpretation of Capability in Terms of ACC Pressure

The predicted ACC pressure can be obtained from the performance curves by entering the curve at the design inlet air temperature and corrected test mass flow of steam ($\dot{m}_{s,T}^c$).

5-6.9 Condensate Temperature Corrections

The adjustment of the condensate temperature is made using condensate temperature correction curves that have to be submitted by the ACC supplier if the condensate temperature is guaranteed. The condensate temperature correction curves should consist of the condensate temperature as function of the ACC pressure and total steam flow rate (expressed in percentage of design steam flow rate). The steam flow rate should vary between 80% and 120% of the design steam flow rate and the ACC pressure should vary between the minimum and maximum value that are shown on the ACC performance curves.

5-7 CONDENSATE TEMPERATURE

If the condensate temperature was measured downstream of the condensate pump, it must be corrected to a location in the condensate tank. This correction requires either a measurement or estimate of condensate pump power.

The condensate temperature should be equal or greater than the guaranteed value.

If desired the condensate subcooling may be calculated from the condensate temperature and the condensate pressure, which must either be measured or estimated. Note that the pressure in the condensate tank is not the same as the condenser pressure, due to pressure drop in the steam duct and equalization line.

5-8 OXYGEN CONTENT

If the dissolved oxygen content is guaranteed, the dissolved oxygen concentration at the condensate tank outlet shall be measured and compared with the specified value. See Nonmandatory Appendix F.

5-9 TEST UNCERTAINTY

The performance of the equipment is evaluated based upon the calculated steam quality during the test conditions and measurements of inlet air dry bulb temperature, atmospheric pressure, motor input power, ACC pressure, and condensate flow rate. Each of these variables is measured with test instrumentation but the measurement of each parameter has an associated uncertainty. The amount of error within a measured variable and ultimately the total error in the test result shall be estimated through the application of a post-test uncertainty analysis.

This post-test uncertainty analysis shall be conducted in accordance with subsection 5-10 and the total uncertainty shall be compared to the criteria given in subsection 1-3. It should be noted that the purpose of a post-test uncertainty analysis is to determine the uncertainty of the final test results.

5-10 UNCERTAINTY ANALYSIS

The following stepwise procedure is recommended for performing the uncertainty analysis.

Step 1: Create a data reduction program that will calculate the ACC capability from the measured test parameters. This data reduction program will be very useful for analyzing the multiple hours of test data required by the Code. Spreadsheet software is a useful calculation tool for this program.

Step 2: Estimate the values of the test parameters. For pretest uncertainty analysis, use the design value for condensate flow, fan power, and atmospheric pressure. Estimate the inlet air dry-bulb temperature for the tests and use the ACC performance curves to estimate the ACC pressure. The estimated values of the test parameters form the base case. For post-test uncertainty analysis, use one run of the test data with the median value of inlet air dry-bulb temperature from that test run data.

Step 3: Calculate the systematic standard deviation for each of the test instruments at the base value of the test parameters. This will include the systematic standard deviation of all devices used to convert the parameter measured to an input value for the calculation spreadsheet. For instance, a condensate flow measurement with an orifice would include the following elements:

(a) the calibration standard deviation or manufacturing tolerance for the orifice plate

(b) the calibration standard deviation for the differential pressure transmitter (current loop)

(c) the tolerance of the resistor used to convert the current output to a voltage signal read by the data acquisition system

(d) the systematic standard deviation of the data acquisition system for reading the voltage signal in the measurement range produced by the resistor in the current loop

See ASME PTC 19.5 for complete uncertainty analysis of an orifice. Most instrument calibrations and tolerances are quoted for a 95% confidence level. If this is the case, the systematic standard deviation may be found by dividing the quoted accuracy by 2. The result will be the total instrument standard deviation for each parameter, $b_{\text{par, inst.}}$

Step 4: Define a perturbation increment for each parameter. This is the value by which each parameter can be changed to create a small change in the calculated result. The instrument uncertainty calculated in Step 3 can be used as a guideline for defining the perturbation increment.

Step 5: Sequentially increment each test parameter by the increment defined in Step 4. Calculate the ACC capability using the data reduction program in Step 1 with the incremented value of each individual test parameter and all other parameters set to their base values. The result will be a set of values of ACC capability including the change caused by each test parameter's perturbation.

Step 6: Sequentially decrement each value of a test parameter by the increment defined in Step 4. Calculate the ACC capability using the data reduction program in Step 1 using the decremented value of each individual test parameter and all other parameters set to their base values. The result will be a set of values of ACC capability including the change caused by each test parameter's decreased perturbation.

Step 7: Calculate the sensitivity coefficient for each test parameter by:

$$\theta_{\text{par}} = \frac{\Delta C}{2\Delta x} = \frac{C^{x+\Delta x} - C^{x-\Delta x}}{2\Delta x}$$

where

C = ACC capability

$C^{x+\Delta x}$ = capability with test parameter, par, set to $x + \Delta x$

$C^{x-\Delta x}$ = capability with test parameter, par, set to $x - \Delta x$

x = base value for a test parameter, par

ΔC = incremental change in ACC capability

Δx = incremental change in a test parameter, par

θ_{par} = sensitivity coefficient of capability to parameter, par

Step 8: Calculate spatial systematic standard deviation for ACC pressure by

$$b_{P\text{cond, spatial}} = \frac{S_{P\text{cond, spatial}}}{\sqrt{m}}$$

where

m = number of measurement stations

$S_{P\text{cond, spatial}}$ = standard deviation of the time-averaged ACC pressure readings

The standard deviation of the ACC pressure measurements is calculated by

$$S_{P\text{cond, spatial}} = \sqrt{\frac{\sum_{i=1,m} (p_{\text{cond, avg}} - p_{\text{cond, }i})^2}{m - 1}}$$

where

m = number of measurement stations

$p_{\text{cond, avg}}$ = average ACC pressure for the test

$p_{\text{cond, }i}$ = average ACC pressure at measurement station i

In the case of a pretest uncertainty analysis, the standard deviation for ACC pressure will have to be estimated.

Step 9: Calculate total systematic standard deviation for ACC pressure by:

$$b_{P\text{cond}} = \sqrt{b^2_{P\text{cond, spatial}} + b^2_{P\text{cond, inst}}}$$

Step 10: Repeat Steps 8 and 9 for inlet air dry-bulb temperature.

NOTE: Only ACC pressure and inlet air dry-bulb temperature have spatial components. For all other parameters the systematic uncertainty of the instrument is equal to the total systematic uncertainty for the parameter.

Step 11: Calculate the total systematic standard deviation for the test. In terms of ACC capability, the contribution of each of the measured parameters to the total systematic uncertainty is calculated by:

$$b^c_{\text{par}} = \theta_{\text{par}}\, b_{\text{par}}$$

where

b^c_{par} = parameter uncertainty in terms of ACC capability

b_{par} = parameter uncertainty, parameter units

The overall systematic standard deviation for the test is calculated as the square root of the sum of the squares of the parameter uncertainties:

$$b = \sqrt{\Sigma_{\text{par}=1,\,m}\,(b^c_{\text{par}})^2}$$

Step 12: Calculate the standard deviation of the test capability for the test runs, S.

$$S = \sqrt{\frac{\Sigma_{i=1,N}\,(\bar{C} - C_i)^2}{N - 1}}$$

where

$\bar{C}$ = average ACC capability for all test runs

C_i = ACC capability for test run i

N = total number of test runs

Step 13: Calculate the total test uncertainty.

$$U_{95} = t_{N-1}\sqrt{b^2 + \frac{S^2}{N}}$$

where

N = number of test runs

S = standard deviation of the ACC capability of the test runs

t_{N-1} = Student's t value (two tailed) for 95% confidence and $N-1$ degrees of freedom

This equation is based on the assumption that random uncertainty term S^2/N is large compared to the systematic uncertainty term, b^2. If this assumption is not valid, the degrees of freedom may be adjusted by the method presented in ASME PTC 19.1, Nonmandatory Appendix B.

Section 6
Report of Results

At a minimum the test report should include the following distinctive sections:

(a) Executive Summary containing

(1) brief description of the object, result, and conclusions reached

(2) signature of test director(s)

(3) signature of reviewer(s)

(4) approval signature(s)

(b) Detailed report of

(1) authorization for the tests, their object, contractual obligations and guarantees, stipulated agreements, by whom the test is directed, and the representative parties to the test

(2) description of the equipment tested and any other auxiliary apparatus, the operation of which may influence the test result

(3) method of test, giving arrangement of testing equipment, instruments used and their location, operating conditions, and complete description of methods of measurement not prescribed by the individual code

(4) summary of measurements and observations

(5) methods of calculation from observed data and calculation of probable uncertainty

(6) correction factors to be applied because of deviations, if any, of test conditions from those specified

(7) primary measurement uncertainties, including method of application

(8) test performances stated under the following headings:

(a) test results computed on the basis of the test operating conditions, instrument calibrations only having been applied

(b) test results corrected to specified conditions if test operating conditions have deviated from those specified

(9) tabular and graphical presentation of the test results

(10) discussion and details of the test results uncertainties

(11) discussion of the test, its results, and conclusions

(c) appendices and illustrations to clarify description of the of the circumstances, equipment, and methodology of the test; description of methods of calibrations of instruments; outline of details of calculations including a sample set of computations, descriptions, and statements depicting special testing apparatus; results of preliminary inspections and trials; and any supporting information required to make the report a complete, self-contained document of the entire undertaking.

NONMANDATORY APPENDIX A
SAMPLE CALCULATIONS OF PERFORMANCE

The following example demonstrates and verifies the information provided in subsections 5-3 through 5-6 of this Code. These sections describe the information requirements, the computational methods, and the comparisons to be made in order to determine ACC performance from test data and to compare the test performance to the guarantee performance for a specified design.

The following material along with the accompanying charts and tables show a worked example based on design information and field test data provided by a vendor for an actual case.

A-1 DESIGN DATA

Design and performance guarantee information specified in subsection 5-4 is given in Table A-1.

A-2 TEST DATA

A-2.1 Test Conditions

See Table A-2.1.

A-2.2 Test Results

Test data were supplied for each minute over a test period of 4 hr and 20 min (2:00 A.M. to 6:20 A.M.). Figures A-2.2-1 through A-2.2-4 show plots of the condensate flow, the condenser pressure, the inlet air temperature and the wind speed at one-minute intervals during the test period.

The following three points are noteworthy:

(a) The wind speed during the test varied from 1.8 m/s to 5.4 m/s, averaging 3.7 m/s.

(b) The condensate flow was quite constant over the test varying from 248 kg/s (892 metric tons/hr) to 256 kg/s (923 metric tons/hr), averaging 251.3 kg/s (904.8 metric tons/hr).

(c) The inlet air temperature fell from 15.2°C to 13.2°C over the test period.

Table A-2.2 shows the averaged values for the entire test period and for each one-hour interval. The illustrative example that follows is based on the values averaged for Hour 4 (5:00 A.M. to 6:00 A.M.).

A-3 CALCULATIONS

A-3.1 Design Point Calculations

(a) LMTD (para. 5-5.1). See Table A-3.1-1.

$$LMTD = Q/(U \times A)$$

A = heat exchange area, m^2
h_{fg} = latent heat of vaporization at design backpressure, J/kg
$\dot{m}$ = design steam mass flow rate, kg/s
Q = ACC heat load, W
= $\dot{m} \times x \times h_{fg}$
U = overall heat transfer coefficient, W/m^2–K
x = design steam quality

(b) Number of Transfer Units (NTU) (para. 5-5.2). See Table A-3.1-2.

$$NTU = (T_o - T_i)/LMTD$$

(c) Gamma Factor (Para. 5-5.3)

$$\Gamma = NTU/(e^{\mathrm{NTU}} - 1) = 0.315$$

For adjustment of test data, see subsection 5-6.

A-3.2 ACC Performance Curves (Para. 5-6.2)

Performance curves provided by the vendor are shown as Fig. A-3.2-1. No trend line equations were provided. Therefore, the values have been read off the curves rather than calculated.

Figure A-3.2-2 shows the performance curves, replotted as Condenser Pressure (kPa) vs. ACC Inlet Temperature (°C) with Percent of Design Turbine Exhaust Steam Flow (%) as a parameter. (See Nonmandatory Appendix B, Description of Performance Curves.)

A-4 CORRECTIONS

A-4.1 Correction for Steam Quality (Para. 5-6.3)

See Table A-4.1.

$$f_x = \frac{x_T}{x_G}$$

x_G = steam quality at guarantee conditions, kg/kg
x_T = steam quality at test conditions, kg/kg

A-4.2 Correction for Atmospheric Pressure (Para. 5-6.4)

See Table A-4.2.

$$f_p = \left[\frac{p_T}{p_G}(1 - \Gamma) + \Gamma\left(\frac{p_T}{p_G}\right)^{m_k}\right]^{-1}$$

m_k = 0.45 (assumed; see above)
p_G = design barometric pressure, kPa
p_T = test atmospheric pressure, kPa
Γ = 0.315 (from para. 5-5.3)

A-4.3 Correction for Fan Power (Para. 5-6.5)

See Table A-4.3.

$$f_{fp} = \left(\frac{W_T^c}{W_G}\right)^{\frac{-1}{3-n}}\left[(1-\Gamma)+\Gamma\left(\frac{W_T^c}{W_G}\right)^{\frac{m_k-1}{3-n}}\right]^{-1}$$

n = 0.33 (assumed; see above)
W_T^c = test fan power corrected for inlet air conditions, kW
W_G = guarantee fan power, kW

$$W_T^c/W_T = (\rho_G/\rho_T)$$

W_T = test fan power
ρ_G = inlet air density at guarantee conditions, kg/m^3
ρ_T = inlet air density at test conditions,kg/m^3

$$\rho_G/\rho_T = (p_G/p_T)\,(T_T + 273.15)/(T_G + 273.15)$$

A-4.4 Correction for Condenser Pressure and Inlet Air Temperature (Para. 5-6.6)

See Table A-4.4.

$$f_{pc} = \dot{m}_{\text{guarantee}} \,/\, \dot{m}_{\text{performance curves}}$$

$\dot{m}_{\text{guarantee}}$ = guarantee steam mass flow rate, kg/s
$\dot{m}_{\text{performance curves}}$ = steam flow rate from performance curves, kg/s

The steam flow rate from the performance curves is found by entering the vendor-supplied performance curves (Fig. A-3.2-2) at the test conditions for inlet air temperature and condenser pressure from Table A-2.2. Using the Hour 4 values from Table A-2.2, gives a Test Point of the following:

Test inlet air temperature = 13.5°C

Test condenser pressure = 11.4 kPa

Scaling from the curves for an ACC Inlet Air Dry-Bulb Temperature of 13.5°C yields the following:

at 90% of design flow: condenser pressure = 10.7 kPa

at 100% of design flow: condenser pressure = 12.4 kPa

Linear interpolation gives that at the test backpressure of 11.4 kPa, the expected steam flow would be 94.1% of design or 236.9 kg/s.

A-4.5 Computation of ACC Capability in Terms of Steam Flow (Para. 5-6.7)

See Table A-4.5. Capability is given as the ratio of the corrected test steam flow and the guarantee steam flow.

$$C = \dot{m}_{s,T}^c/\dot{m}_{s,G} \times 100\%$$

$\dot{m}_{s,T}^c$ = test mass flow of steam, kg/s, (corrected for quality, atmospheric pressure, fan power, inlet air temperature and turbocondenser pressure)
$\dot{m}_{s,G}$ = guaranteed steam mass flow rate, kg/s

The corrected test steam flow, $\dot{m}_{s,T}^c$, is the measured test steam flow times the correction factors for quality, atmospheric pressure, fan power and inlet air/condenser pressure from Tables A-4.1, A-4.2, A-4.3, and A-4.4, respectively.

The measured test steam flow is obtained from Table A-3.1-1. For the "Stable Period" case, the measured condensate flow = 250.8 kg/s.

Table A-1 Design and Guarantee Information

Quantity	Value	Comments
Vendor Provided Design/Guarantee Data:		
Atmospheric pressure, kPa	101.3	. . .
Inlet air temperature, °C	9.5	. . .
Outlet air temperature, °C	37.82	. . .
Total fan power at motor terminals, kW	2,943	If given at MCC, it must be corrected per Nonmandatory Appendix L
Condenser pressure, kPa	10.57	. . .
Turbine exhaust steam flow, kg/s	251.758	. . .
Exhaust steam quality	0.932	. . .
Latent heat of vaporization, kJ/kg	2,390.3	From ASME Steam Tables for p_{sat} = 10.57 kPa
Heat exchange surface (total air side), m^2	1,150,643	. . .
Heat transfer coefficient, W/m^2–°C (based on total air-side area at clean conditions)	34.49	. . .
m_k (assumed)	0.45	. . .
n (assumed)	0.33	. . .
Also Provided:		
Steam enthalpy, kJ/kg (saturated steam at 10.57 kPa)	2,422.9	From ASME Steam Tables
Wind speed, m/s	≤5	. . .
Vendor-generated performance curves	. . .	See Nonmandatory Appendix B

Table A-2.1 Test Conditions

Quantity (Assumed/Measured Data)	Value
Atmospheric pressure, kPa	101.3
Steam quality	> 0.932 [Note (1)]
Fan power, kW	3 109

NOTE:
(1) Assumed to be 0.95 in example calculation.

Fig. A-2.2-1 Total Steam Flow

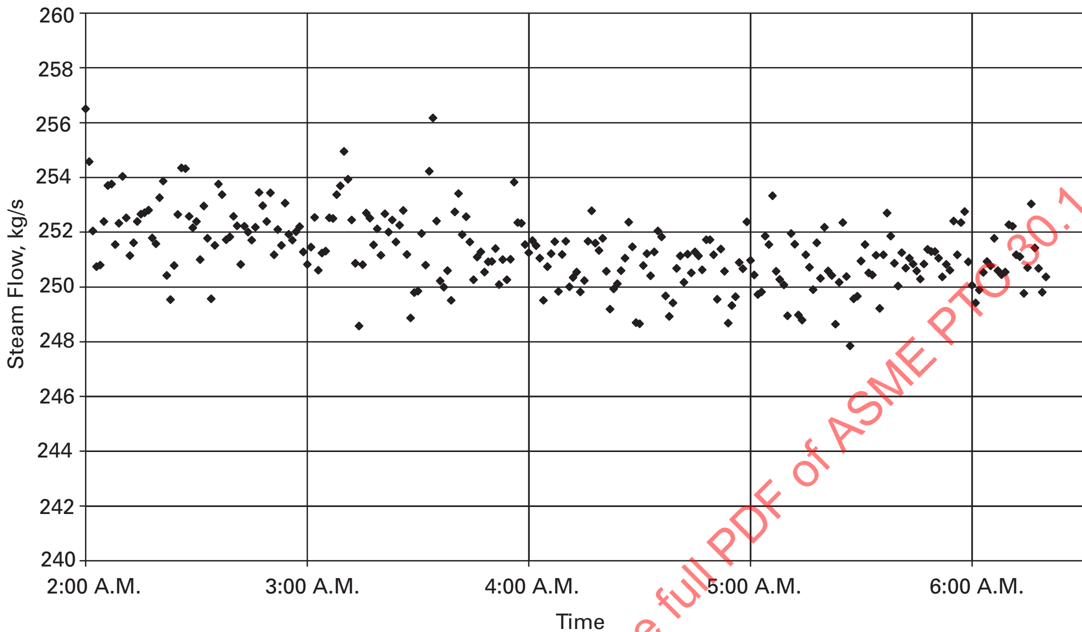


Fig. A-2.2-2 Condenser Pressure

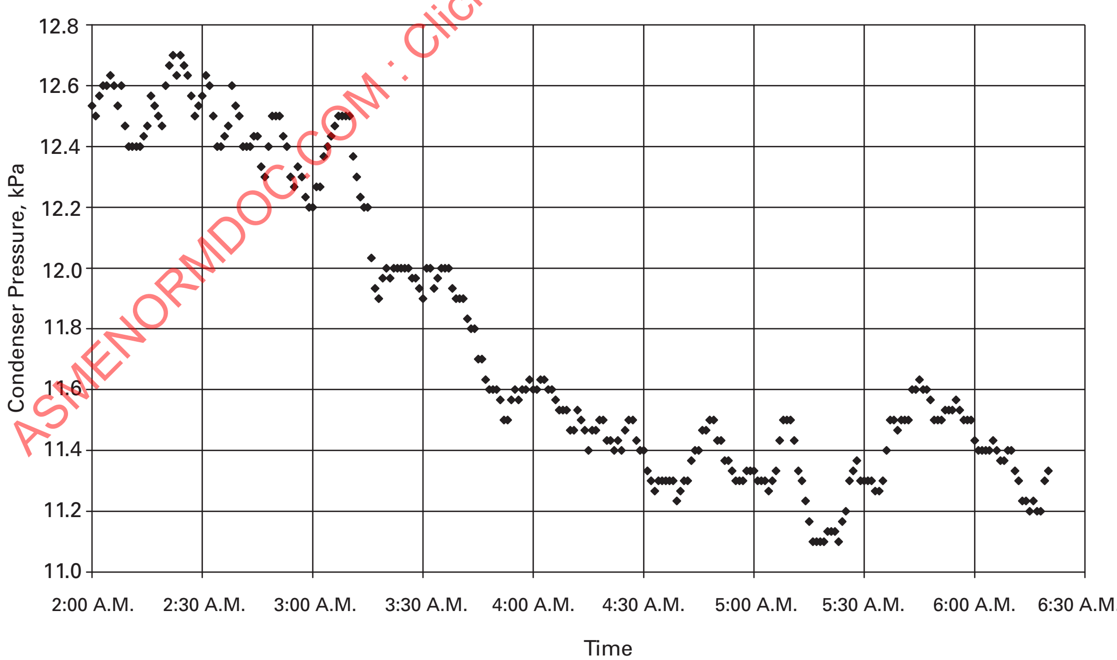


Fig. A-2.2-3 Inlet Air Temperature

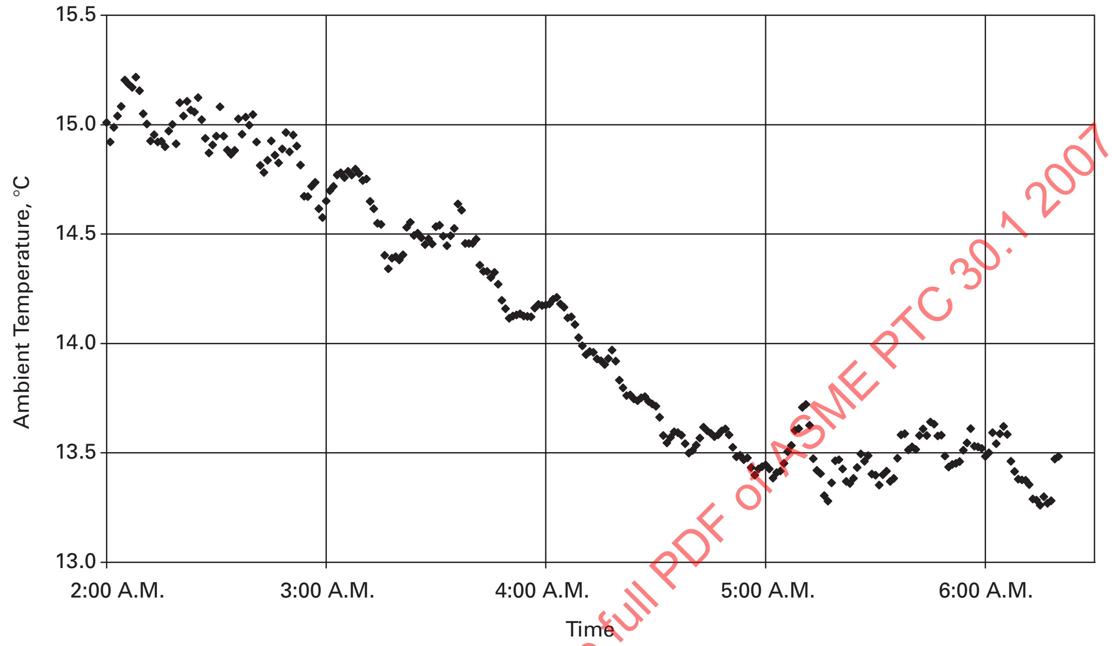


Fig. A-2.2-4 Wind Speed

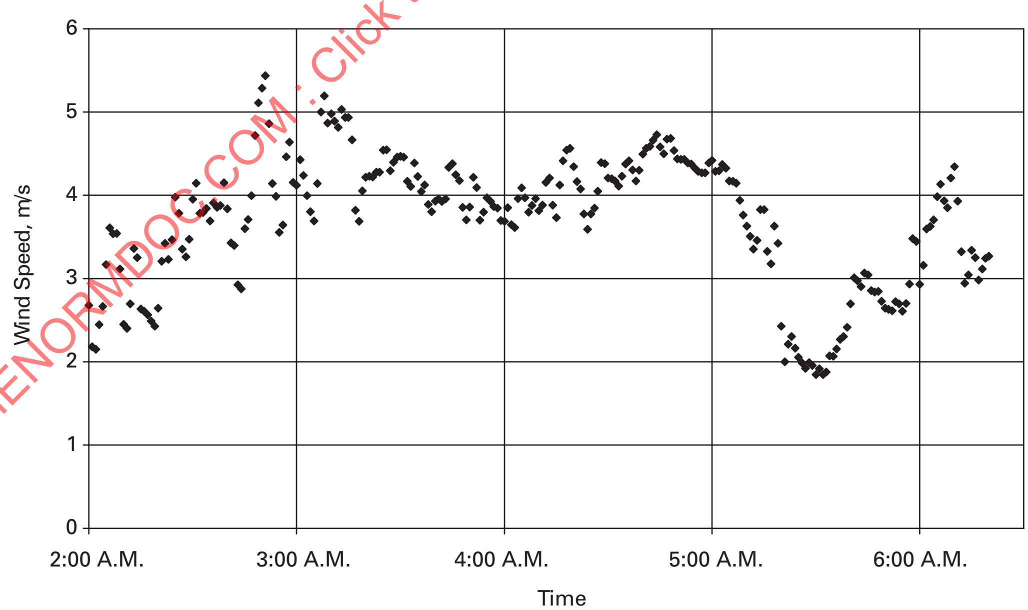


Table A-2.2 Averaged Test Results

Test Period	Condensate Flow, kg/s (metric tons/hr)	Condenser Pressure, kPa (bara)	Air Inlet Temperature, °C	Wind Speed, m/s
Entire Test	251.3 (904.8)	11.8 (0.118)	14.1	3.7
Hour 1	252.3 (908.3)	12.5 (0.125)	14.9	3.5
Hour 2	251.7 (906.1)	12.0 (0.12)	14.5	4.2
Hour 3	250.7 (902.6)	14.0 (0.14)	13.7	4.2
Hour 4	250.8 (902.8)	11.4 (0.114)	13.5	2.9

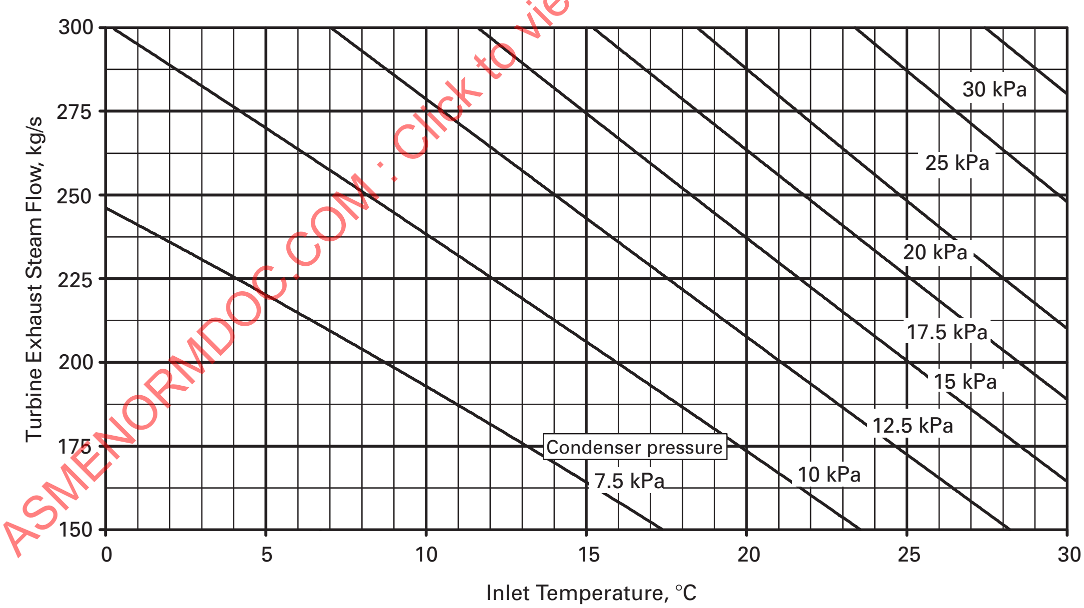
Table A-3.1-1 Calculation of LMTD

Heat of vaporization, kJ/kg (at 10.57 kPa)	2 390.3
Steam mass flow, kg/s (= turbine exhaust flow × exhaust quality)	234.6
Heat load, kW	560 856.3
LMTD, °C	14.13

Table A-3.1-2 Calculation of NTU

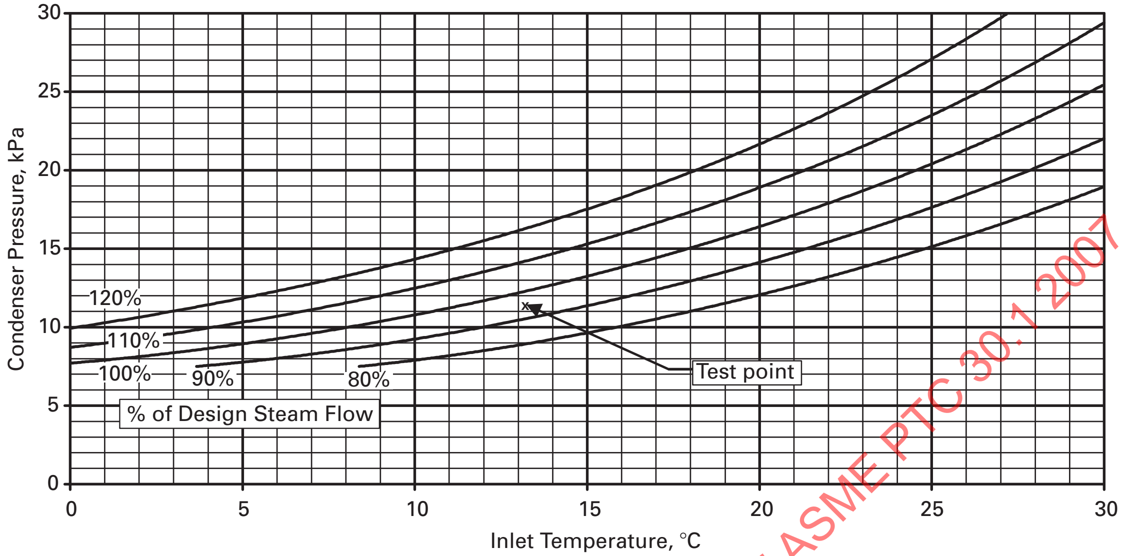
Air inlet temperature, °C	9.5
Air outlet temperature, °C	37.62
LMTD, °C	14.13
NTU	1.99

Fig. A-3.2-1 Vendor-Supplied ACC Performance Curves



GENERAL NOTE: Design conditions are as follows:
Turbine exhaust steam flow = 251.758 kg/s
Condenser pressure = 10.57 kPa
Inlet air temperature = 9.5°C
Turbine exhaust steam quality = 0.932
ACC fan power = 2,943 kW
Site elevation = Sea level
Atmospheric pressure = 101.3 kPa

Fig. A-3.2-2 Replotted Performance Curves



ACC Base Performance Curves

GENERAL NOTE: Design conditions are as follows:

Turbine exhaust steam flow	= 251.758 kg/s
Condenser pressure	= 10.57 kPa
Inlet air temperature	= 9.5°C
Turbine exhaust steam quality	= 0.932
ACC fan power	= 2,943 kW
Site elevation	= Sea level
Atmospheric pressure	= 101.3 kPa

Table A-4.1 Correction for Steam Quality

Test quality (assumed)	0.95
Guarantee quality	0.932
Quality correction, f_x	1.019

Table A-4.2 Correction for Atmospheric Pressure

Test atmospheric pressure, kPa	101.3
Guarantee atmospheric pressure, kPa	102.3
Atmospheric pressure correction, f_p	1.0

Table A-4.3 Fan Power Correction

Guarantee fan power, W_G, kW	2,943
Test fan power, W_G, kW	3,109
Test atmospheric pressure, kPa	101.3
Guarantee atmospheric pressure, kPa	101.3
Test inlet air temperature, °C	13.49
Guarantee inlet air temperature, °C	9.5
W_T^C/W_T	1.014
W_T^C, kW	3,153
f_{fp}	0.979

Table A-4.4 Condenser Pressure and Inlet Air Correction

$\dot{m}_{\text{performance curves}}$, kg/s	236.9
$\dot{m}_{\text{guarantee}}$, kg/s	251.758
f_p	1.063

Table A-4.5 Computation of ACC Capability

Guarantee steam mass flow, kg/s	251.758
Test steam mass flow, kg/s	250.8
Quality correction	1.019
Atmospheric pressure correction	1.0
Fan power correction	0.978
Inlet air and condenser pressure correction	1.063
Corrected test steam mass flow, kg/s	265.75
Capability	105.6%

NONMANDATORY APPENDIX B
DESCRIPTION OF PERFORMANCE CURVES

B-1 INTRODUCTION

Subsection 5-4 of this Code requires that the ACC supplier provide, among other items, a set of ACC performance curves. The following section describes a set of performance curves and illustrates how they are to be interpreted.

B-1.1 Description of Curves

(a) Performance data provide the relationships among

(1) condenser pressure

(2) turbine exhaust steam flow

(3) ACC inlet air dry-bulb temperature

for specified design over a reasonable range of operating conditions.

(b) The specified design conditions include

(1) condenser pressure

(2) turbine exhaust steam flow

(3) ACC inlet air dry-bulb temperature

(4) site elevation (atmospheric pressure)

(5) ACC fan power (at motor terminals)

(c) The range of conditions would typically be

(1) for turbine exhaust steam flow: 80%, 90%, 100%, 110%, and 120% of design flow

(2) for condenser pressure: 5 kPa to 30 kPa (~1.5 in. HgA to 9 in. HgA)

(3) for ACC inlet air dry-bulb temperature: −10°C to 40°C (~15°F to 105°F)

B-1.2 Format

Performance data is typically provided graphically but can also be provided as tabular data or in equation form at the option of the purchaser.

B-1.2.1 Primary Format. The primary format for graphical presentation, which was chosen for use in Section 5, Computation of Results, and Nonmandatory Appendix A, Sample Calculations of Performance, is a plot of Condenser Pressure vs. ACC Inlet Air Dry-Bulb Temperature with Turbine Exhaust Steam Flow as a parameter. A typical set of performance curves in this format expressed in SI units is shown in Fig. B-1.2.1-1. Specific design conditions are denoted in the figure.

The identical set of curves is shown in U.S. customary units in Fig. B-1.2.1-2 for convenience of reference.

B-1.2.2 Alternative Formats. Alternative and equivalent graphical formats are frequently used as follows:

(a) ACC (Turbine Exhaust) Steam Flow vs. Air Inlet Temperature with Condenser Pressure as a parameter (shown in Fig. B-1.2.2-1)

(b) Condenser Pressure vs. ACC (Turbine Exhaust) Steam Flow with ACC Inlet Air Temperature as a parameter (shown in Fig. B-1.2.2-2)

B-1.2.3 Other Representations — Tabular Data. The data underlying the curves in Fig. B-1.2.1-1 may be presented in Table B-1.2.3.

B-1.2.4 Other Representations — Equation Format. The performance curves may also be presented in equation form. They are typically given as second to fourth order polynomials. The curves of Fig. B-1.2.1-1 are presented below as fourth order polynomials with one equation for each of the five curves, each representing a different turbine exhaust steam flow (80%, 90%, 100%, 110% and 120% of the design steam flow).

In these equations,

P_b = condenser pressure, kPa

T_i = ACC inlet air temperature, °C

(a) 80% of design flow (for 10°C < T_i < 40°C)

$$P_b = 0.000008\,T_i^4 - 0.000581\,T_i^3 + 0.029106\,T_i^2 - 0.166921\,T_i + 7.159822 \quad \text{(B-1)}$$

(b) 90% of design flow (for 5°C < T_i < 40°C)

$$P_b = 0.000005\,T_i^4 - 0.000257\,T_i^3 + 0.017538\,T_i^2 + 0.065837\,T_i + 7.035217 \quad \text{(B-2)}$$

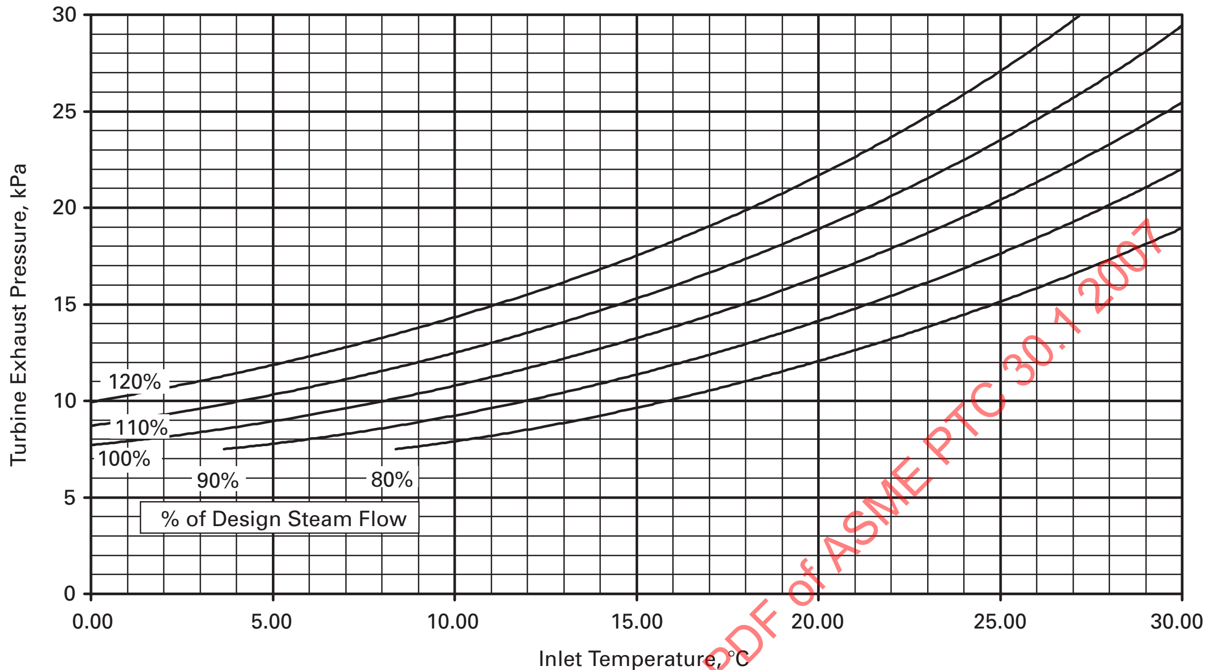
(c) 100% of design flow (for 0°C < T_i < 35°C)

$$P_b = 0.000004\,T_i^4 - 0.000112\,T_i^3 + 0.013074\,T_i^2 + 0.183833\,T_i + 7.706393 \quad \text{(B-3)}$$

(d) 110% of design flow (for −5°C < T_i < 30°C)

$$P_b = 0.000005\,T_i^4 - 0.000046\,T_i^3 + 0.011199\,T_i^2 + 0.265391\,T_i + 8.709746 \quad \text{(B-4)}$$

Fig. B-1.2.1-1 Example ACC Performance Curves, Primary Format (SI Units)



GENERAL NOTE: Design conditions are as follows:

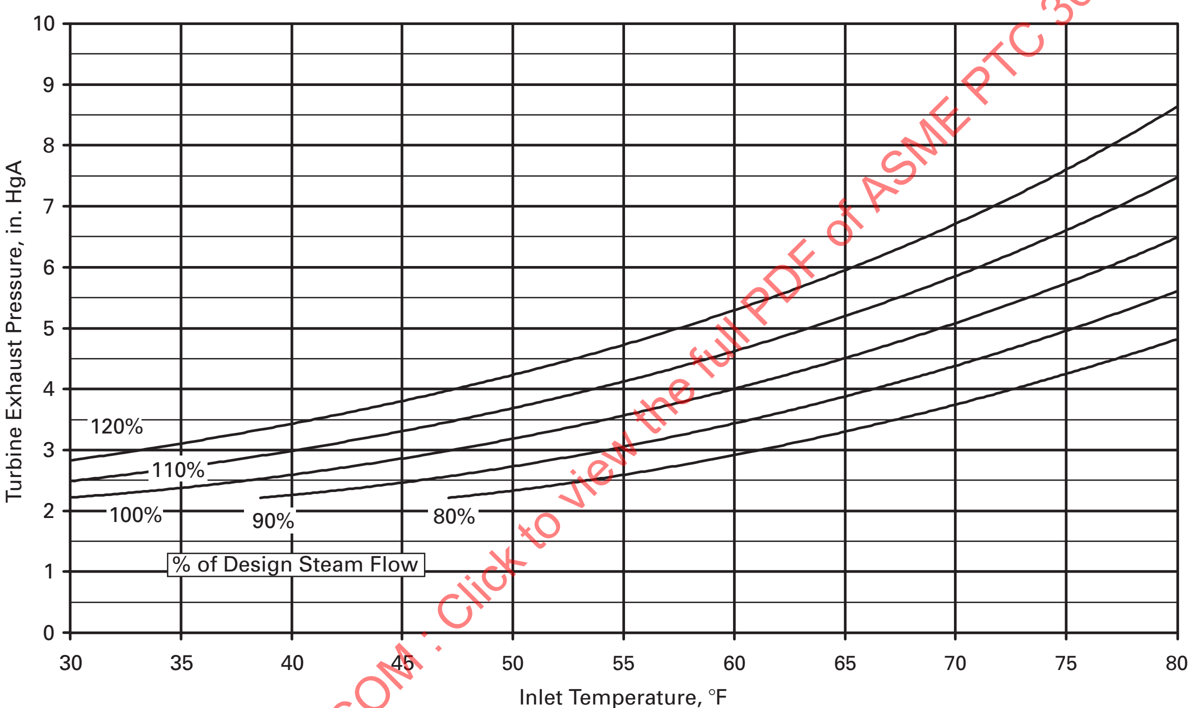
Turbine exhaust steam flow	=	251.758 kg/s
Turbine exhaust pressure	=	10.57 kPa
Inlet air temperature	=	9.5°C
Turbine exhaust steam quality	=	0.932
ACC fan power	=	2,943 kW
Site elevation	=	Sea level (101.3 kPa)

(*e*) 120% of design flow (for $-10°C < T_i < 30°C$)

$$P_b = 0.000006\, T_i^4 + 0.000011\, T_i^3 + 0.009926\, T_i^2 + 0.333281\, T_i + 9.933474 \qquad \text{(B-5)}$$

CAUTION: If the performance data is provided in equation form, caution must be taken that the equations not be extrapolated beyond their range of applicability. When the information is provided in graphical or tabular form, the range of applicability is usually visually implicit in the extent of the curves or the range of values listed in the table. The equations, however, might be inadvertently used with values beyond their limits of validity. (For example, temperature and flow combinations giving operating backpressure below 5 kPa may give erroneous results.)

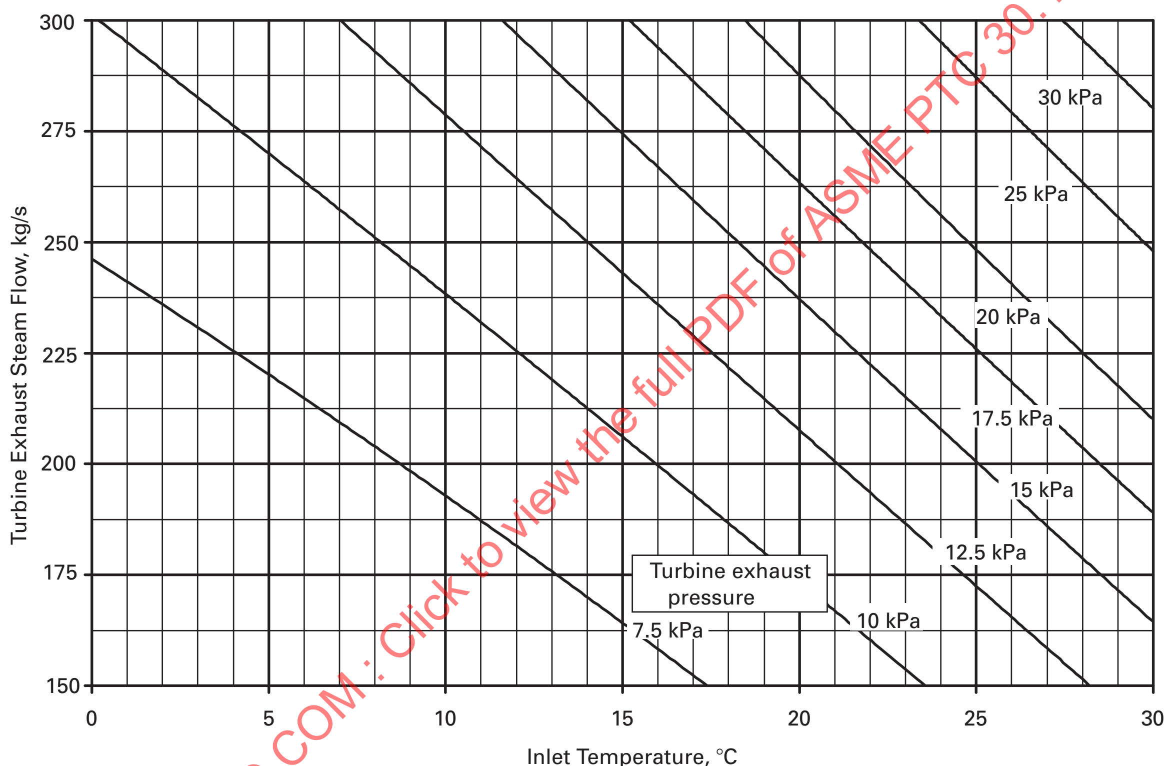
Fig. B-1.2.1-2 Example ACC Performance Curves, Primary Format (U.S. Customary Units)



GENERAL NOTE: Design conditions are as follows:

Turbine exhaust steam flow = 1,998,080 lb/hr
Turbine exhaust pressure = 3.12 in. HgA
Inlet air temperature = 49.1°F
Turbine exhaust steam quality = 0.932
ACC fan power = 3,945 hp
Site elevation = Sea level
Atmospheric pressure = 14.7 psia

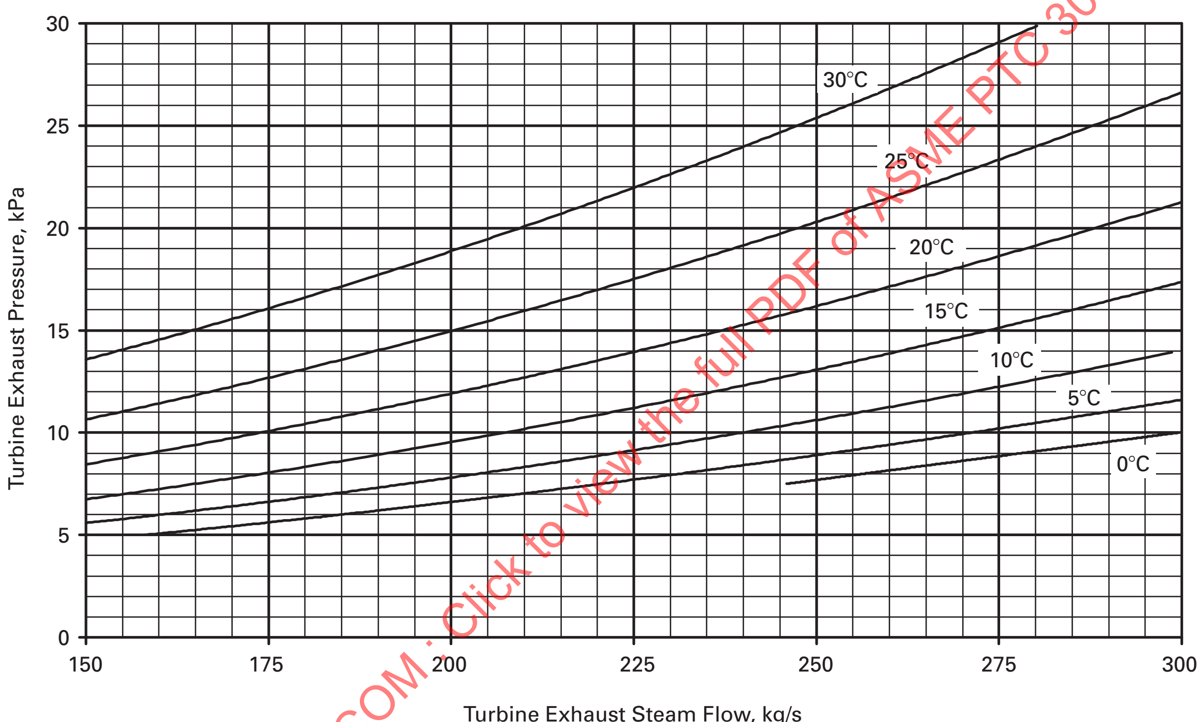
Fig. B-1.2.2-1 Alternative ACC Performance Curves (Steam Flow vs. Inlet Temperature) — SI Units



GENERAL NOTE: Design conditions are as follows:

Turbine exhaust steam flow	=	251.758 kg/s
Turbine exhaust pressure	=	10.57 kPa
Inlet air temperature	=	9.5°C
Turbine exhaust steam quality	=	0.932
ACC fan power	=	2,943 kW
Site elevation	=	Sea level
Atmospheric pressure	=	101.3 kPa

Fig. B-1.2.2-2 Alternate ACC Performance Curves (Condenser Pressure vs. Steam Flow) — SI Units



GENERAL NOTE: Design conditions are as follows:

Turbine exhaust steam flow	=	251.758 kg/s
Turbine exhaust pressure	=	10.57 kPa
Inlet air temperature	=	9.5°C
Turbine exhaust steam quality	=	0.932
ACC fan power	=	2,943 kW
Site elevation	=	Sea level
Atmospheric pressure	=	101.3 kPa

Table B-1.2.3 Performance Data—Tabular Format

Turbine Exhaust Steam Flow, % of Design	Turbine Exhaust Pressure, kPa for ACC Inlet Temperature, °C										
	−10	−5	0	5	10	15	20	25	30	35	40
80	. . .	. . .	. . .	. . .	7.91	9.66	12.11	15.24	19.16	24.09	30.37
90	. . .	. . .	. . .	7.77	9.24	11.35	14.11	17.58	21.91	27.31	34.08
100	. . .	. . .	7.71	8.94	10.78	13.23	16.36	20.29	25.20	31.36	. . .
110	. . .	7.67	8.71	10.31	12.49	15.31	18.93	23.58	29.56	. . .	. . .
120	7.64	8.52	9.93	11.85	14.33	17.51	21.62	26.98	34.02	. . .	. . .

GENERAL NOTE: Design conditions are as follows:

Turbine exhaust steam flow = 251.758 kg/s
Turbine exhaust pressure = 10.57 kPa
ACC inlet air temperature = 9.5°C
Turbine exhaust steam quality = 0.932
ACC fan power = 2,943 kW
Site elevation = Sea level (101.3 kPa)
Atmospheric pressure = 101.3 kPa

NONMANDATORY APPENDIX C
UNCERTAINTY ANALYSIS EXAMPLE

C-1 SENSITIVITY FACTORS

Using the data in the example in Nonmandatory Appendix A, the sensitivity factors for each of the test parameters were calculated by incrementally changing the test parameters about average test result.

$$\theta_{par} = \frac{\Delta C}{2\Delta x} = \frac{C^{x+\Delta x} - C^{x-\Delta x}}{2\Delta x}$$

where

C = ACC capability
$C^{x+\Delta x}$ = capability with test parameter, par, set to $x + \Delta x$
$C^{x-\Delta x}$ = capability with test parameter, par, set to $x - \Delta x$
x = base value for a test parameter, par
ΔC = incremental change in condenser capability
Δx = incremental change in a test parameter, par
θ_{par} = sensitivity factor of capability to parameter, par

A data reduction spreadsheet was used to generate capability values at the incremented test parameter values. Table C-1-1 summarizes the result of the sensitivity analysis.

The instrumental uncertainty for each of the test parameters was calculated by procedures detailed in subsection 5-10. The instrumental uncertainty of each of the test parameters is summarized in Table C-1-2.

Condenser pressure and inlet air temperature are measured by an array of instruments that are averaged. The average value for such parameters is subject to spatial bias. The spatial systematic for ACC pressure is calculated by

$$b_{P\text{cond, spatial}} = \frac{S_{P\text{cond, spatial}}}{\sqrt{m}}$$

$$b_{P\text{cond, spatial}} = \frac{S_{T\text{air, spatial}}}{\sqrt{m}}$$

where

m = number of measurement stations
$S_{P\text{cond, spatial}}$ = standard deviation of the time averaged ACC pressure readings

The standard deviation of the ACC pressure measurements is calculated by

$$S_{P\text{cond, spatial}} = \sqrt{\frac{\sum_{i=1,m} (p_{\text{cond, avg}} - p_{\text{cond}, i})^2}{m-1}}$$

where

m = number of measurement stations
$p_{\text{cond, avg}}$ = average ACC pressure for the test
$p_{\text{cond}, i}$ = average ACC pressure at measurement station i

The ACC pressure measurements are illustrated in Fig. C-1. For four ACC pressure measurements, $m = 4$. The standard deviation of the ACC pressure measurements was 0.123 kPa.

$$b_{P\text{cond}} = \frac{0.123}{\sqrt{4}} = 0.062 \text{ kPa}$$

The total systematic uncertainty for ACC pressure was calculated by the square root of the sum of the squares of the systematic uncertainty of the pressure transmitter and the spatial systematic uncertainty.

$$b_{P\text{cond}} = \sqrt{b^2_{P\text{cond, inst}} + b^2_{P\text{cond, spatial}}} = \sqrt{(0.035)^2 + (0.062)^2}$$
$$= 0.071 \text{ kPa}$$

The spatial systematic uncertainty and the total systematic uncertainty for inlet air temperature was calculated in a similar manner. The calculation of the spatial uncertainty for air temperature is illustrated in Table C-1-3.

The systematic uncertainty, in terms of ACC capability, is calculated by multiplying the parameter uncertainty by the sensitivity factor:

$$b^c_{par} = \theta_{par} b_{par}$$

where

b^c_{par} = parameter uncertainty in terms of ACC capability
b_{par} = parameter uncertainty, parameter units

The overall systematic uncertainty for the test is calculated the square root of the sum of the squares of the parameter uncertainties:

$$b = \sqrt{\Sigma_{\text{par}=1,m} (b^c_{\text{par}})^2}$$

The systematic uncertainty calculations are summarized in Table C-1-2.

The total uncertainty for the series of test runs is calculated by:

$$U = t_{N-1}\sqrt{b^2 + \frac{S^2}{N}}$$

where

N = number of test runs

S = the standard deviation of the ACC capability of the test runs

t_{N-1} = student's t value (two tailed) for 95% confidence and $N - 1$ degrees of freedom

A series of six test runs was performed. The ACC capabilities for the test runs are summarized in Table C-1-4.

The overall uncertainty in the ACC capability for the test series is:

$$U = 2.57\sqrt{(0.79)^2 + \frac{(2.131)^2}{N}} = 3.02\%$$

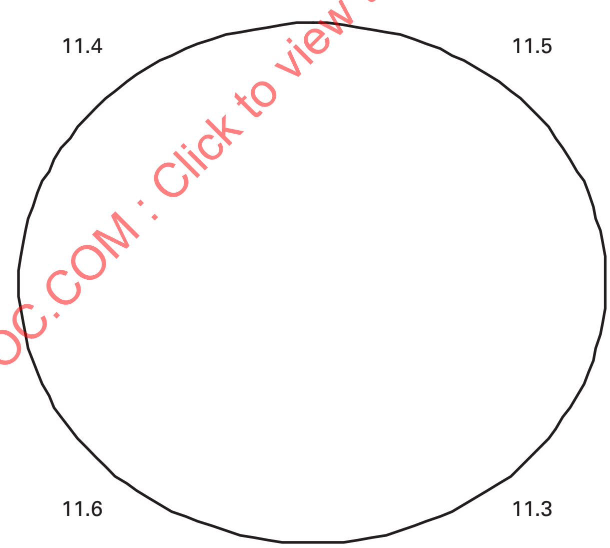
Table C-1-1 Sensitivity Factors for Test Parameters

Parameter	Units	Test Value	Increment	Capability +	Capability −	Sensitivity
Inlet air temperature	°C	13.49	1	108.27	102.35	2.96
Atmospheric pressure	kPa	101.3	1	104.72	105.72	−0.5
Fan power at MCC	kW	3 109	100	104.19	106.29	−0.0105
Exhaust pressure	kPa	11.4	0.2	103.93	106.56	−6.575
Turbine exhaust flow	kg/sec	250.8	2.5	106.27	104.17	0.42
Steam quality	. . .	0.95	0.01	106.33	104.11	111
Capability	%	105.22	. . .	. . .	. . .	. . .

Table C-1-2 Instrument Uncertainty of Test Parameters

Parameter	Units	Instrumental Uncertainty	Spatial Uncertainty	Systematic Uncertainty	Capability Sensitivity	Capability Uncertainty
Inlet air temperature	°C	0.05	0.154	0.161	2.96	0.48
Atmospheric pressure	kPa	0.1	. . .	0.1	−0.5	−0.05
Fan power at MCC	kW	23.3	. . .	23.3	−0.0105	−0.24
Exhaust pressure	kPa	0.035	0.061	0.072	−6.575	−0.47
Turbine exhaust flow	kg/sec	0.820	. . .	0.820	0.42	0.34
Exhaust steam quality	. . .	. . .	. . .	0	111	0.00
Capability	%	. . .	. . .	. . .	. . .	0.79

Fig. C-1 ACC Pressure Measurements



Average	11.4 kPa	p_{cond}
Standard	0.12 kPa	$S_{Pcond,spatial}$
Number	4	m
Student's *t* value	3.182	$t_{95\%,m-1}$
Spatial	0.195 kPa	

$$B_{Pcond,spatial} = \frac{t_{n-1} S_{Pcond,\,spatial}}{\sqrt{m}}$$

Table C-1-3 Test Summary

Test Run	Capability
1	104.66
2	103.20
3	104.77
4	99.73
5	105.25
6	105.22
Average	103.80
S	2.131
N	6
$t_{95,N-1}$	2.570581835

Table C-1-4 Spatial Variation for Inlet Air Temperature

Air Inlet Temperature

4A 11.12	4B 10.60	4C 10.59	4D 10.66	4E 11.18
3A 10.85	3B 10.50	3C 10.46	3D 10.45	3E 10.88
2A 11.24	2B 11.36	2C 11.00	2D 11.02	2E 11.07
1A 11.60	1B 11.80	1C 12.41	1D 11.88	1E 12.40

4F 10.68	4G 10.76	4H 10.67	4I 10.70	4J 12.74
3F 11.15	3G 10.90	3H 10.82	3I 10.80	3J 11.36
2F 11.67	2G 11.30	2H 10.92	2I 10.69	2J 10.84
1F 12.18	1G 12.90	1H 13.07	1I 11.67	1J 15.60

Average $\left(T_{\text{air, inlet}}\right)$ $= 11.49°\text{C}$

Standard Deviation $\left(S_{T_{\text{air, spatial}}}\right)$ $= 0.977°\text{C}$

Number (m) $= 40$

Student's *t* $(t_{95\%,\ m-1})$ $= 2.023$

Spatial Uncertainty $\left(B_{T_{\text{air, spatial}}}\right)$ $= 0.312°\text{C}$

$$B_{T_{\text{air, spatial}}} = \frac{t_{m-1} S_{T_{\text{air, spatial}}}}{\sqrt{m}}$$

NONMANDATORY APPENDIX D
DERIVATION OF EXPONENTS m_k AND n

D-1 INTRODUCTION OF TERMINOLOGY AND DEFINITIONS

Figure D-1 defines some basic quantities for an ACC. Standard definitions from heat transfer terminology give

$$Q = \dot{m}_a c_p (T_{a,o} - T_{a,i}) \tag{D-1}$$

$$\Delta T_{\ln m} = Q/UA \tag{D-2}$$

$$NTU \equiv (T_{a,o} - T_{a,i})/\Delta T_{\ln m} = UA/\dot{m}_a c_p \tag{D-3}$$

where

c_p = specific heat of air

It is convenient for future derivations to define a "performance coefficient" and a "gamma factor" as

$$ITD = T_{\text{cond}} - T_{a,i} \tag{D-4a}$$

$$\Phi \equiv (T_{a,o} - T_{a,i})/ITD \tag{D-4b}$$

$$\Gamma \equiv NTU\,(e^{NTU} - 1) \tag{D-4c}$$

It can be shown from eq. (D-3) and the definition of $\Delta T_{\ln m}$ that

$$\Phi = 1 - e^{-NTU} \tag{D-5}$$

The correction factors introduced in subection 5-6 are used to adjust the performance measured during test to the performance that would have been obtained if the test had been run at design conditions. All the correction factors take the form of a factor by which the measured steam flow is multiplied to obtain the steam flow that could have been condensed at design conditions.

D-2 CORRECTION FACTORS

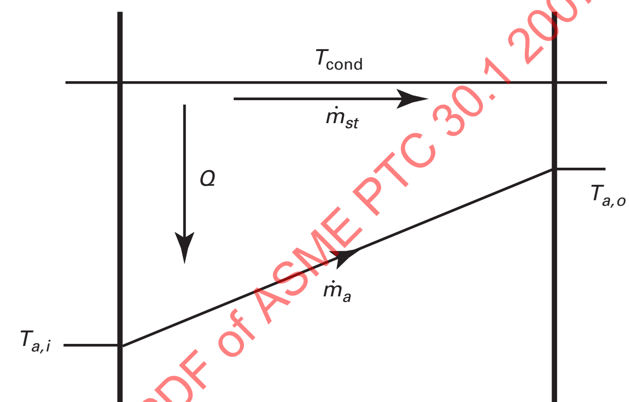
The correction factors for atmospheric pressure f_p and for fan motor power f_{fp} are defined in terms of two exponents, m_k and n. These are defined below and then the equations for f_p and f_{fp} are derived in terms of measured quantities and the exponents.

The exponents are defined by their use in simplified approximations to the variation of

(a) the overall heat transfer coefficient with air flow, m_k and

(b) the friction factor for air flow through the finned tube bundles, n

Fig. D-1 Definition of Variables



D-2.1 Exponent m_k

Exponent m_k is defined by the approximating equation for overall heat transfer coefficient as a function of air-side Reynolds Number (Re) as

$$U \propto K\,(R_e)^{m_k} \tag{D-6}$$

This approximation is justified as follows. Expressing the overall heat transfer coefficient in terms of the individual heat transfer resistances between the condensing steam and the cooling air yields

$$U = h_{\text{air}}\left\{1 + \frac{\left[\frac{A}{A_i}\left(\frac{1}{h_i} + \frac{\delta}{k}\right) + R_f\right]}{\frac{1}{h_i}}\right\}^{-1} \tag{D-7}$$

where

A = air-side heat transfer area, m^2
A_i = steam-side heat transfer area, m^2)
h_{air} = air-side heat transfer coefficient, W/m^2–K
h_i = steam-side heat transfer coefficient, W/m^2–K
k = tube wall thermal conductivity, W/m–K
R_f = air-side fouling coefficient (m^2–K/W)
δ = tube wall thickness, m

Since the dominant resistance is the air side resistance

$$\frac{\left[\frac{A}{A_i}\left(\frac{1}{h_i} + \frac{\delta}{k}\right) + R_f\right]}{\frac{1}{h_i}} << 1 \tag{D-8}$$

implying that

$$\frac{1}{U} \cong \frac{1}{h_{\text{air}}} \quad \text{(D-9)}$$

From standard correlations

$$h_{\text{air}} \propto Re^m \quad \text{(D-10)}$$

where m represents a typical exponent. Therefore, it is reasonable to approximate the overall heat transfer coefficient similarly by

$$U \propto Re^{m_k} \quad \text{(D-11)}$$

Taking the derivative of both with respect to Re and rearranging yields

$$m_k \approx m\,(U/h_{\text{air}}) \quad \text{(D-12)}$$

Again from standard data references on extended surfaces m is frequently in the range of 0.3 to 0.6. Therefore, an approximation of $m_k = 0.45$ is a reasonable one.

D-2.2 Exponent *n*

Exponent n is defined by the approximating equation for friction factor as a function of air-side Reynolds Number (Re) as

$$f \propto (Re)^{-n} \quad \text{(D-13)}$$

From standard references for extended surface heat exchangers, n typically falls in a range between 0.25 and 0.45. Therefore, an assumed value (unless otherwise specified by the vendor) of 0.33 is reasonable.

D-2.3 Derivation of Correction Factor for Atmospheric Pressure, f_p

For this correction factor, only variations in atmospheric pressure are considered. Fan speed inlet air temperature and condensing temperature are assumed constant. Fan motor power is handled in a separate correction.

The correction factor for atmospheric pressure is given by

$$f_p = \dot{m}_{st,\,G}/\dot{m}_{st,\,T} \quad \text{(D-14)}$$

evaluated at constant conditions except for atmospheric pressure.

$$\dot{m}_{st} \propto Q = \dot{m}_a\, c_p\, (T_{a,o} - T_{a,i}) \quad \text{(D-15)}$$

$$\dot{m} = q\rho_a \quad \text{(D-16)}$$

where

q = volumetric flow rate of air

$$T_{a,\,o} - T_{a,\,i} = \Phi\,(T_{\text{cond}} - T_{a,\,i}) \quad \text{(D-17)}$$

At constant fan speed, ambient temperature and condensing temperature, q, $T_{a,\,i}$, and T_{cond} are constant and

$$\dot{m}_{st} \propto \rho_a \Phi \quad \text{(D-18)}$$

$$f_p = \dot{m}_{st,G}/\dot{m}_{st,T} = [\rho_T/\rho_G]^{-1}\,[\Phi_T/\Phi_G]^{-1} \quad \text{(D-19)}$$

Expressing Φ in terms of physical quantities, beginning with eq. (D-5)

$$\Phi = 1 - e^{-NTU} \quad \text{(D-20)}$$

$$\Phi_T/\Phi_G = \frac{1 - e^{-NTU,T}}{1 - e^{-NTU,G}} \quad \text{(D-21)}$$

Rearranging and using the approximation that $1 - e^{-\varepsilon} = \varepsilon$ for $\varepsilon \ll 1$, yields

$$\Phi_T/\Phi_G = 1 - \frac{NTU_G}{e^{NTU,G} - 1} + \frac{NTU_G\,(NTU_T\,/\,NTU_G)}{e^{NTU,G} - 1} \quad \text{(D-22)}$$

From eq. (D-4b),

$$\Gamma \equiv NTU_G/(e^{NTU,G} - 1) \quad \text{(D-23)}$$

giving

$$\Phi_T/\Phi_G = 1 - \Gamma + \Gamma\left(\frac{NTU_T}{NTU_G}\right) \quad \text{(D-24)}$$

From the definition of NTU [eq. (D-3)] and with A and c_p constant,

$$\left(\frac{NTU_T}{NTU_G}\right) \propto (U_T/U_G)(\dot{m}_{a,\,G}/\dot{m}_{a,\,T}) \quad \text{(D-25)}$$

From the derivation of m_k in eq. (D-12),

$$U \propto (Re)^{m_k} \propto (\rho_a\, q)^{m_k} \quad \text{(D-26)}$$

and from eq. (D-16)

$$(\dot{m}_{a,G}/\dot{m}_{a,T}) = (\rho_{a,\,G}/\rho_{a,\,T})(q_{a,\,G}/q_{a,\,T}) \quad \text{(D-27)}$$

At constant fan speed, the volumetric air flow, q, is constant so

$$\frac{NTU_T}{NTU_G} = [(\rho_{a,\,T}/\rho_{a,\,G})^{m_k}](\rho_{a,\,G}/\rho_{a,\,T}) \quad \text{(D-28)}$$

At constant air temperature, air density is proportional to atmospheric pressure, p, giving

$$NTU_T/NTU_G = (p_T/p_G)^{m_k - 1} \quad \text{(D-29)}$$

Substituting in eq. (D-24)

$$\Phi_T/\Phi_G = 1 - \Gamma + \Gamma[(p_T/p_G)^{m_k-1}] \qquad \text{(D-30)}$$

and eq. (D-19) becomes

$$f_p = \dot{m}_{st,G}/\dot{m}_{st,T}$$

$$= [p_T/p_G]^{-1}\left(1 - \Gamma + \Gamma[(p_T/p_G)^{m_k-1}]\right)^{-1} \qquad \text{(D-31)}$$

$$f_p = [(p_T/p_G)(1 - \Gamma) + \Gamma(p_T/p_G)^{m_k}]^{-1} \qquad \text{(D-32)}$$

as given in para. 5-6.4.

D-2.4 Correction for Fan Motor Power, f_{fp}

The adjustment to fan motor power is done in two steps. First, the fan motor power measured under test conditions, W_T, is corrected for ambient conditions, specifically atmospheric pressure and air temperature, if they are different from design conditions. Second, when the corrected fan power, W_T^c, is different from the guarantee fan power, W_G, the effect of this difference is determined.

Fan motor power is given by

$$W = \Delta pq/\eta_f \qquad \text{(D-33)}$$

where η_f is the motor fan efficiency and will be assumed to be constant for operation near the design point.

From

$$\Delta p \propto f\rho_a q^2 \qquad \text{(D-34a)}$$

$$f \propto Re^{-n} \qquad \text{(D-34b)}$$

$$Re \propto \rho_a q \qquad \text{(D-34c)}$$

where f represents the friction due to configuration of the air path, fan power is given by

$$W \propto \rho^{1-n}/q^{n-3} \qquad \text{(D-35)}$$

Therefore,

$$W_T^c/W_T = (\rho_G/\rho_T)^{1-n}(q_T/q_G)^{n-3} \qquad \text{(D-36)}$$

For constant fan speed, $q_T/q_G = 1$ and from the perfect gas law, $\rho \propto p/T$, yielding

$$W_T^c/W_T = \left[(\rho_G/\rho_T)\left(\frac{T_T + 273.15}{T_G + 273.15}\right)\right]^{1-n} \qquad \text{(D-37)}$$

Having corrected the test fan power for atmospheric pressure and temperature, it is now necessary to adjust the ACC performance to account for the difference between W_T^c and W_G. This derivation proceeds along similar lines to the correction for atmospheric pressure in para. D-2.3.

$$f_{fp} = \dot{m}_{st,G}/\dot{m}_{st,W_T^c} \qquad \text{(D-38)}$$

The effect of air density has already been corrected for in W_T^c so the only remaining effects are changes in volumetric air flow and the performance coefficient. Therefore, in this case, eq. (D-38) becomes

$$f_{fp} = (q_T^c/q_G)^{-1}(\Phi_T^c/\Phi_G)^{-1} \qquad \text{(D-39)}$$

Again expressing Φ in physical quantities and following eqs. (D-20) through (D-24), eq. (D-25) becomes

$$\frac{NTU_T^c}{NTU_G} \propto (U_T^c/U_G)(q_G/q_T^c) = (q_T^c/q_G)^{m_k}(q_G/q_T^c) \qquad \text{(D-40)}$$

Following eqs. (D-26) and (D-27) with $\rho_{a,G}/\rho_{a,T^c} = 1$

$$\frac{NTU_T^c}{NTU_G} = (q_G/q_T^c)^{1-m_k} \qquad \text{(D-41)}$$

From eq. (D-35) with ρ_a = constant

$$\frac{NTU_T^c}{NTU_G} = (W_T^c/W_G)^{\frac{1-m_k}{n-3}} \qquad \text{(D-42)}$$

Substituting into eq. (D-24)

$$\Phi_T/\Phi_G = 1 - \Gamma + \Gamma(W_T^c/W_G)^{\frac{1-m_k}{n-3}} \qquad \text{(D-43)}$$

$$q_T^c/q_G = (W_G/W_T^c)^{\frac{1}{n-3}} \qquad \text{(D-44)}$$

Combining and rearranging gives

$$f_{fp} = (W_T^c/W_G)^{\frac{-1}{3-n}}\left[(1 - \Gamma) + \Gamma(W_T^c/W_G)^{\frac{m_k-1}{n-3}}\right]^{-1} \qquad \text{(D-45)}$$

as in para. 5-6.5.

NONMANDATORY APPENDIX E
CALCULATION OF THE STEAM QUALITY AT TEST CONDITIONS

In general, steam quality will vary with the steam turbine exhaust pressure. Measured performance test values of steam turbine exhaust pressure may be different from the design value. As a result the steam quality may deviate from its design value requiring that a correction be made (see paras. 5-6.3 and A-4.1 for the calculation of the steam quality correction factor). If the steam turbine exhaust pressure at the test conditions is lower than its design value, the expected steam quality should be lower than its design value and vice versa.

The following correction procedure assumes that the slope of the enthalpy versus entropy line for the steam turbine is independent of the exhaust pressure, inlet temperature, pressure, and flow. This is equivalent to assuming a constant isentropic efficiency for the steam turbine. Studies using cycle models indicated that the error associated with calculating the steam quality based on this assumption is less than 1%.

Step 1: From the steam turbine heat balance diagram corresponding to the ACC design conditions, obtain the inlet temperature and pressure for the low pressure turbine as well as the turbine exhaust enthalpy and pressure.

Step 2: Using steam tables or equivalent software determine the specific enthalpy and specific entropy of the low pressure turbine inlet steam.

Step 3: Calculate the design value of the steam quality of the Steam Turbine exhaust steam by:

$$x_d = \frac{h_{e,d} - h_{l,d}}{h_{v,d} - h_{l,d}}$$

where

$h_{e,d}$ = the design value for the specific enthalpy of the exhaust steam

$h_{l,d}$ = the specific enthalpy of saturated liquid at the exhaust pressure

$h_{v,d}$ = the specific enthalpy of saturated vapor at the exhaust pressure

x_d = the design value of the steam quality of the turbine exhaust steam

This value should correspond to the design value for the ACC.

Step 4: Calculate the design value of the specific entropy of the Steam Turbine exhaust steam at design conditions:

$$s_{e,d} = x_d\, s_{v,d} + (1 - x_d)\, s_{L,d}$$

where

$s_{e,d}$ = the specific entropy of Steam Turbine exhaust steam at design conditions

$s_{L,d}$ = the specific entropy of saturated liquid at the Steam Turbine exhaust pressure

$s_{v,d}$ = the specific entropy of saturated vapor at the Steam Turbine exhaust pressure

Step 5: Calculate the slope of the "expansion line" by

$$m_e = \frac{h_{i,d} - h_{e,d}}{s_{i,d} - s_{e,d}}$$

where

$h_{i,d}$ = design value of the specific enthalpy of the low pressure turbine inlet steam

m_e = slope of the expansion line

$s_{i,d}$ = design value of the specific entropy of the low pressure turbine inlet steam

NOTE: If a Steam Turbine test on the unit has been performed, the slope of the expansion line may be calculated by substituting actual values for specific enthalpy and specific entropy at the inlet and outlet from the steam turbine test.

Step 6: Using steam tables or equivalent software, determine the specific enthalpy and specific entropy of the low pressure steam turbine exhaust steam at the test conditions for saturated liquid and saturated steam, respectively.

Step 7: Calculate the quality of the steam at the test condition by:

$$x_T = \frac{m_e(s_{e,d} - s_{L,T}) + h_{L,T} - h_{e,d}}{m_e(s_{v,T} - s_{L,T}) + h_{L,T} - h_{v,T}}$$

where

$h_{e,d}$ = design value of the specific enthalpy for the low pressure outlet steam

$h_{L,T}$ = specific enthalpy of saturated liquid for the test value of the exhaust pressure

$h_{v,T}$ = specific enthalpy of saturated vapor for the test value of the exhaust pressure

$s_{e,d}$ = design value of the specific entropy for the low pressure outlet steam
$s_{L,T}$ = specific entropy of saturated liquid for the test value of the exhaust pressure
$s_{v,T}$ = specific entropy of saturated vapor for the test value of the exhaust pressure

NOTE: If no design values for the specific enthalpy and specific entropy of the low pressure turbine inlet steam are known, a typical value of −1 500 K for the slope of the expansion line can be assumed. A sensitivity analysis has shown that a large variation in the value of the slope (−1 000 K to −3 000 K) of the expansion line has only almost no impact on estimated value of the steam quality under test conditions (error less than 0.5%). Please refer to the example below as well.

EXAMPLE:

(1) Design value for the steam turbine exhaust pressure = 20 000 Pa
(2) Design value of the steam quality of the turbine exhaust steam = 95.6%
(3) Test value of the steam turbine exhaust pressure = 10 000 Pa
(4) Assumed value for the slope of the expansion line = −1 500 K

Calculation of the design value of the specific enthalpy at the steam turbine exhaust:

$h_{e,d}$ = 0.956 × 2 609.9 kJ/kg + (1 − 0.956) × 251.45 kJ/kg = 2 506.1 kJ/kg
$h_{L,d}$ = 251.45 (from steam tables for saturated liquid at 20 000 Pa)
$h_{v,d}$ = 2 609.9 kJ/kg (from steam tables for saturated steam at 20 000 Pa)
x_d = 0.956 (steam quality of the steam turbine exhaust steam at design conditions)

Calculation of the design value of the specific entropy at the steam turbine exhaust:

$s_{L,d}$ = 0.8321 kJ/kg/K (from steam tables for saturated liquid at 20 000 Pa)
$s_{v,d}$ = 7.9094 kJ/kg/K (from steam tables for saturated steam at 20 000 Pa)
x_d = 0.956

Using the equation $s_{e,d} = x_d\, s_{v,d} + (1 - x_d)\, s_{L,d}$, it is determined that:

$$s_{e,d} = 0.956 \times 7.9094 \text{ kJ/kg/K} + (1 - 0.956) \times 0.8321 \text{ kJ/kg/K} = 7.5980 \text{ kJ/kg/K}$$

From the steam tables at the steam turbine exhaust test pressure of 10,000 Pa:

$h_{L,T}$ = 191.83 kJ/kg
$h_{v,T}$ = 2 584.8 kJ/kg
$s_{L,T}$ = 0.6493 kJ/kg/K
$s_{v,T}$ = 8.1511 kJ/kg/K

Using m_e = −1 500 K and the equation above, it can be found:

$$x_T = \frac{m_e(s_{e,d} - s_{L,T}) + h_{L,T} - h_{e,d}}{m_e(s_{v,T} - s_{L,T}) + h_{L,T} - h_{v,T}} = 0.933$$

It can be noticed that the end result for the steam quality at test conditions (x_T) would not have minimally varied (less than 0.4%) by using any value between −1 000 K and −3 000 K for the slope (m_e) of the expansion line.

NONMANDATORY APPENDIX F TEST CALCULATIONS FOR DISSOLVED OXYGEN DETERMINATION

F-1 INTRODUCTION

If required to meet a dissolved oxygen guarantee, dissolved oxygen will be measured in accordance with ASME PTC 12.3, Performance Test Code on Deaerators.

F-2 SAMPLING FREQUENCY

Dissolved oxygen samples shall be taken once per test run, as a minimum.

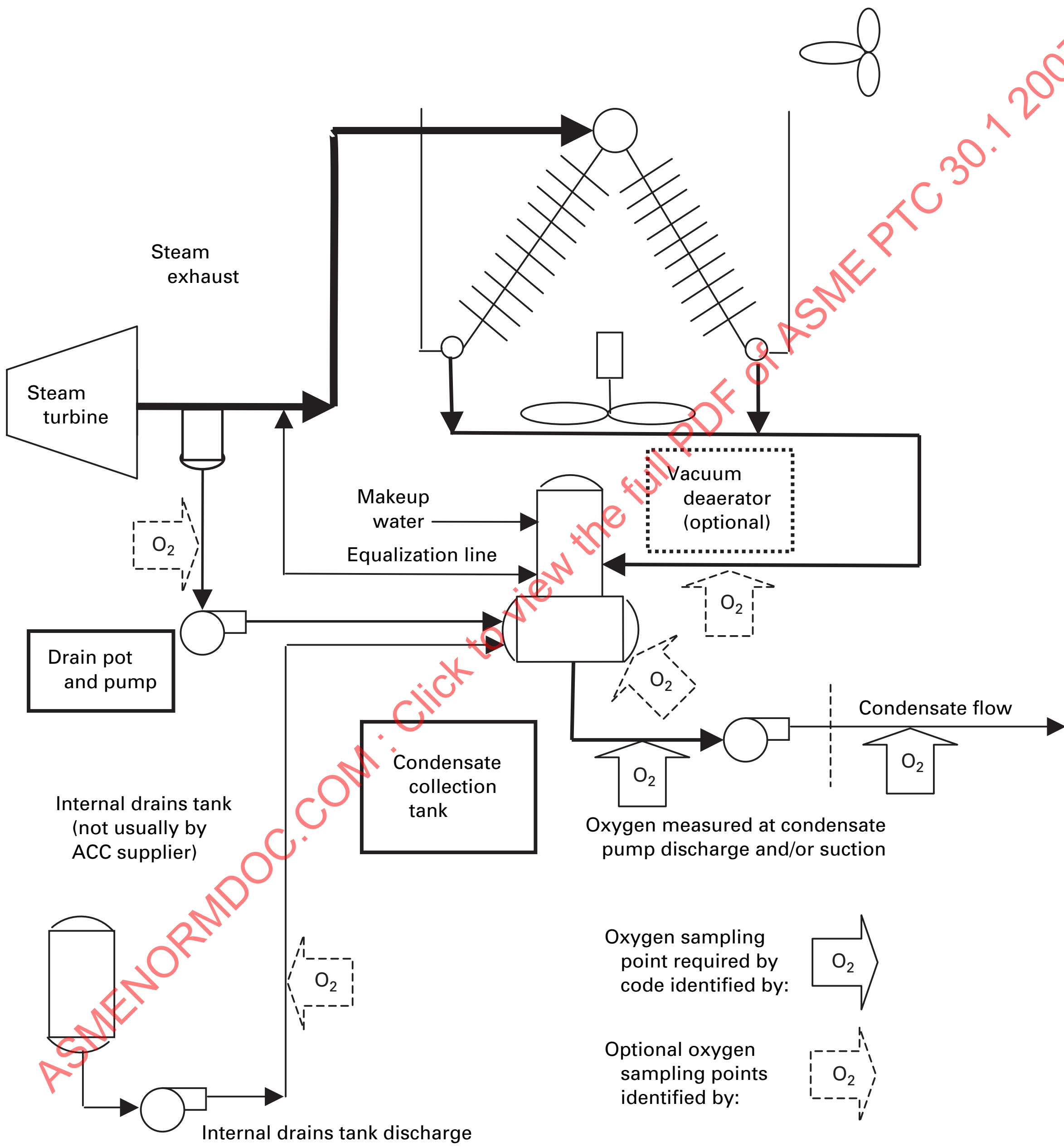
F-3 SAMPLE LOCATION

Dissolved oxygen sample locations are shown on Fig. F-3.

F-4 SAMPLE METHODS

Sample methods for dissolved oxygen are identified in ASME PTC 12.3. Alternatively, ASTM D 5462, Standard Test Method On-Line Measurement of Low Level Dissolved Oxygen in Water or ASTM D 5543, Standard Test Method for Low Level Dissolved Oxygen in Water may be used.

Fig. F-3 Oxygen Sampling Location



NONMANDATORY APPENDIX G
DATA SHEETS

See Forms G-1 and G-1M on the following pages.

Form G-1 Air-Cooled Condenser Data Sheet

Manufacturer / Model	*	*	
Type of ACC [Note (1)]	*		
Tag Equipment Number(s)	**		
Location: City / State / Country	**	**	
Site Elevation (feet above sea level)	**		
Wind Speed (mph) / Direction	**	**	
Seismic Zone	**		
Turbine Exhaust Direction	**		
Max. Avail. Space for ACC (ft×ft) / Distance fr. Turbine Bldg (ft) [Note (2)]	**	**	
Tube Side Performance	**Guaranteed Ambient**	**Maximum Ambient**	**Minimum Ambient**
Turbine Exhaust Steam Flow (lb/hr) [Note (3)]			
Turbine Exhaust Enthalpy (Btu/lb) [Note (4)]			
Condenser Inlet Pressure (in. HgA) [Note (5)]	*	*	*
Turbine Back Pressure (in. HgA) [Note (6)]			
ACC Inlet Enthalpy (Btu/lb) [Note (7)]			
Duct Pressure Drop (in. HgA)	*	*	*
Noncondensable Exhaust Flow (acfm)	*	*	*
ACC Inlet Temperature (°F)	*	*	*
Outlet Temperature (°F)	*	*	*
ACC Inlet Steam Flow (lb/hr)	*	*	*
Outlet Condensate Flow (lb/hr)	*	*	*
Steam-side Pressure Drop (in. HgA)	*	*	*
Condensate Storage Tank Pressure (in. HgA)	*	*	*
Condensate Temperature Leaving Tank (°F)	*	*	*
Condensate Tank Flow (lb/hr)	*	*	*
Temp Δ: Turbine Exhaust − Condensate Return (°F)	*	*	*
Drain Pot Tank Flow (lb/hr)	*	*	*
ACC Makeup Flow (lb/hr)	*	*	*
Total Heat Duty Exchanged (MMBtu/hr)	*	*	*
Air Side Performance			
Inlet Dry Bulb Temperature (°F)			
Outlet Temperature (°F)	*	*	*
Temperature Rise (°F)	*	*	*
Total Air Mass Flow (lb/hr)	*	*	*
Total Air Flow per Fan (acfm)	*	*	*
Static Pressure (in. H_2O)	*	*	*
Face Velocity (ft/min)	*	*	*
Inlet Air Velocity (ft/min)	*	*	*
Recirculation Air − Temperature Δ (°F)	*	*	*
Design			
Number of Cells: Primary / Secondary	*	*	
Number of Cells per Street / Number of Streets per Block	*	*	
Number of Sides Open per Block / Number of Blocks On-site	*	*	
Cell Size: Primary / Secondary (ft×ft)	*	*	
Pressure: Design / Test (psig)	*	*	
ACC Dimensions: Length / Width / Height (ft)	*	*	*
Effective Surface Area LMTD (ft^2) / (°F)	*	*	
Heat Exchanged / Transfer Rate (MMBtu/hr) / (Btu/hr−ft^2−°F)	*	*	
Number of Tube Rows: Primary / Secondary	*	*	
Main Steam Duct: Outside Diameter / Length (ft)	*	*	
OD: Branch to Street / Equalizing Line / Condensate Header (in.×in.×in.)	*	*	*
Steam Duct Corrosion Allowance (in.)			
Tube Wall Thickness / Pitch / Length (in.) / ° / (ft)	*	*	*
Primary Tube Bundle Size: Length / Width / Height (ft×ft×ft)	*	*	*

	AIR-COOLED CONDENSER ***PROJECT NAME***	Job No:				
		MR No:				
		Attachment				
		SHEET	1	OF	2	

NOTES: * Seller to fill in all empty boxes. If not applicable, Seller to indicate by marking "N/A" in appropriate box.
** Buyer to fill in empty boxes.

Form G-1 Air-Cooled Condenser Data Sheet (Cont'd)

Secondary Tube Bundle Size: Length / Width / Height (ft×ft×ft)	*	*	*
Fin: Type / Pitch (in)/ °	*		*
Fin Sizes: Height / Length / Thickness (in.×in.×in.)	*	*	*
Tube Material / Fin Material	*		*
Number of Tubes per Bundle: Primary / Secondary	*		*
Steam Duct Material	*		
Number of Air Removal Nozzles: Primary / Secondary	*		*
Structure Surface Preparation	*		*
Fans			
Manufacturer / Model	*		*
Diameter / RPM (in.) / (rpm)	*		*
Material: Blade/Hub	*		*
Blade Pitch/Number of Blades per Fan (°/)	*		*
Driver			
Manufacturer / Model	*		*
Type: Single Speed / Two Speed / No. of Windings / VFD	*	*	*
Voltage / Phase / Hertz			
HP / RPM	*		*
Total Power Required (kW): Target / Guarantee Case (kW)	*		*
Gear Reducer			
Manufacturer / Model	*		*
Type	*		
Ratio	*		
Service Factor	*		
Vibration Switches: Manufacturer / Model	*		*
Deaerator (if required)			
Deaerator: Type / Model	*		*
Deaerator: Maximum Make-up Flow	*		
Deaerator: Steam Source	*		
Hugging and Holding			
Hugger: Pump or Ejector / Manufacturer / Model [Note (8)]		*	*
Pressure: Time Req. / Min. Steam Flow (in HgA / min / lb/hr) [Note (9)]			*
Holding: Pump or Ejector / Manufacturer / Model [Note (10)]		*	*
Design Flow / Steam Pressure / Min. Steam Flow (acfm / psig / lb/hr) [Note (11)]	*	*	*
Hogger / Holding: Aux Load Req. (included in guarantee) (kW/kW) [Note (12)]	*		*

NOTES: * Seller to fill in all empty boxes. If not applicable, Seller to indicate by marking "N/A" in appropriate box.
** Buyer to fill in empty boxes.

(1) By seller. 4 × 5 down exhaust, 5 × 4 side exhaust, etc.

(2) By buyer. Distance is from the turbine building where the exhaust duct exits and the closest ACC header flange. This distance should also include the distance from the turbine exhaust and the outer turbine building wall.

(3) By buyer. Exhaust Flow should correspond with each case.

(4) By buyer. Exhaust Enthalpy should correspond with each case.

(5) Condenser Inlet Pressure is by seller. Condenser inlet pressure is the pressure the ACC can accept from the turbine, this may be different from the ACC design pressure because this is at the turbine/ACC interface.

(6) Turbine Back Pressure is by the buyer. Turbine Back Pressure should correspond to one or two guarantee cases.

(7) ACC Inlet Enthalpy is by seller. ACC inlet enthalpy is the enthalpy the ACC can accept from the turbine, this may be different from the ACC design pressure. If so, extra equipment will be needed.

(8) Pump or Ejector is specified by buyer, Manufacturer and Model is by seller.

(9) Hogger Pressure and Time Requirement by buyer. If Pump then pump horsepower should replace minimum steam flow by seller.

(10) Pump or Ejector is specified by buyer. Manufacturer and Model is by seller.

(11) Holding Design Flow and Steam Requirement by seller. If Pump then pump horsepower should replace minimum steam flow by seller.

(12) By seller. kW should already be included in the total aux load guarantee.

	AIR-COOLED CONDENSER *PROJECT NAME*	Job No:	
		MR No:	
		Attachment	
		SHEET	2 OF 2

Form G-1M Air-Cooled Condenser Data Sheet

Manufacturer Model	*	*	
Type of ACC [Note (1)]	*		
Tag Equipment Number(s)	**		
Location: City / State / Country	**	**	
Site Elevation (meters above sea level)	**		
Wind Speed (m/s) / Direction	**	**	
Seismic Zone	**		
Turbine Exhaust Direction	**		
Max. Avail. Space for ACC (m×m) / Distance fr. Turbine Bldg (m) [Note (2)]	**	**	
Tube Side Performance	**Guaranteed Ambient**	**Maximum Ambient**	**Minimum Ambient**
Turbine Exhaust Steam Flow (kg/h) [Note (3)]			
Turbine Exhaust Enthalpy (kJ/kg) [Note (4)]			
Condenser Inlet Pressure (bara) [Note (5)]	*	*	*
Turbine Back Pressure (bara) [Note (6)]			
ACC Inlet Enthalpy (kJ/kg) [Note (7)]			
Duct Pressure Drop (bara)	*	*	*
Noncondensable Exhaust Flow (l/s)	*	*	*
ACC Inlet Temperature (°C)	*	*	*
Outlet Temperature (°C)	*	*	*
ACC Inlet Steam Flow (kg/h)	*	*	*
Outlet Condensate Flow (kg/h)	*	*	*
Steam-side Pressure Drop (bara)	*	*	*
Condensate Storage Tank Pressure (bara)	*	*	*
Condensate Temperature Leaving Tank (°C)	*	*	*
Condensate Tank Flow (kg/h)	*	*	*
Temp Δ: Turbine Exhaust − Condensate Return (°C)	*	*	*
Drain Pot Tank Flow (kg/h)	*	*	*
ACC Makeup Flow (kg/h)	*	*	*
Total Heat Duty Exchanged (MW)	*	*	*
Air Side Performance			
Inlet Dry Bulb Temperature (°C)			
Outlet Temperature (°C)	*	*	*
Temperature Rise (°C)	*	*	*
Total Air Mass Flow (kg/h)	*	*	*
Total Air Flow per Fan (l/s)	*	*	*
Static Pressure (bara)	*	*	*
Face Velocity (m/s)	*	*	*
Inlet Air Velocity (m/s)	*	*	*
Recirculation Air − Temperature Δ (°C)	*	*	*
Design			
Number of Cells: Primary / Secondary	*	*	
Number of Cells per Street / Number of Streets per Block	*	*	
Number of Sides Open per Block / Number of Blocks On-site	*	*	
Cell Size: Primary / Secondary (m×m)	*	*	
Pressure: Design / Test (barg)	*	*	
ACC Dimensions: Length / Width / Height (m×m×m)	*	*	*
Effective Surface Area (m^2) / LMTD (°C)	*	*	
Heat Exchanged / Transfer Rate (MW)/ (kJ/h−m^2−°C)	*	*	
Number of Tube Rows: Primary / Secondary	*	*	
Main Steam Duct: Outside Diameter / Length (m)	*	*	
OD: Branch to Street / Equalizing Line / Condensate Header (mm×mm×mm)	*	*	*
Steam Duct Corrosion Allowance (mm)			
Tube Wall Thickness / Pitch / Length (mm) / ° / (m)	*	*	*
Primary Tube Bundle Size: Length / Width / Height (m×m×m)	*	*	*

	AIR-COOLED CONDENSER ***PROJECT NAME***	Job No:			
		MR No:			
		Attachment			
		SHEET	1	OF	2

NOTES: * Seller to fill in all empty boxes. If not applicable, Seller to indicate by marking "N/A" in appropriate box.
** Buyer to fill in empty boxes.

Form G-1M Air-Cooled Condenser Data Sheet (Cont'd)

Secondary Tube Bundle Size: Length / Width / Height (m×m×m)	*	*	*
Fin: Type / Pitch (mm)/°	*		*
Fin Sizes: Height / Length / Thickness (mm×mm×mm)	*	*	*
Tube Material / Fin Material	*		*
Number of Tubes per Bundle: Primary / Secondary	*		*
Steam Duct Material		*	
Number of Air Removal Nozzles: Primary / Secondary	*		*
Structure Surface Preparation	*		*
Fans			
Manufacturer / Model	*		*
Diameter / RPM (mm) / (rpm)	*		*
Material: Blade/Hub	*		*
Blade Pitch/Number of Blades per Fan (°/)	*		*
Driver			
Manufacturer / Model	*		*
Type: Single Speed / Two Speed / No. of Windings / VFD	*	*	*
Voltage / Phase / Hertz			
kW / RPM (kW / rpm)	*		*
Total Power Required (kW): Target / Guarantee Case (kW/(kW)	*		*
Gear Reducer			
Manufacturer / Model	*		*
Type		*	
Ratio		*	
Service Factor		*	
Vibration Switches: Manufacturer / Model	*		*
Deaerator (if required)			
Deaerator: Type / Model	*		*
Deaerator: Maximum Make-up Flow		*	
Deaerator: Steam Source		*	
Hugging and Holding			
Hugger: Pump or Ejector / Manufacturer / Model [Note (8)]		*	*
Pressure: Time Req. / Min. Steam Flow (bara / min / kg/h) [Note (9)]			*
Holding: Pump or Ejector / Manufacturer / Model [Note (10)]		*	*
Design Flow / Steam Pressure / Min. Steam Flow (acfm / psig / lb/hr) [Note (11)]	*	*	*
Hugger / Holding: Aux Load Req. (included in guarantee) (kW/kW) [Note (12)]	*		*

NOTES: * Seller to fill in all empty boxes. If not applicable, Seller to indicate by marking "N/A" in appropriate box.
** Buyer to fill in empty boxes.

(1) By seller. 4 × 5 down exhaust, 5 × 4 side exhaust, etc.

(2) By buyer. Distance is from the turbine building where the exhaust duct exits and the closest ACC header flange. This distance should also include the distance from the turbine exhaust and the outer turbine building wall.

(3) By buyer. Exhaust Flow should correspond with each case.

(4) By buyer. Exhaust Enthalpy should correspond with each case.

(5) Condenser Inlet Pressure is by seller. Condenser inlet pressure is the pressure the ACC can accept from the turbine, this may be different from the ACC design pressure because this is at the turbine/ACC interface.

(6) Turbine Back Pressure is by the buyer. Turbine Back Pressure should correspond to one or two guarantee cases.

(7) ACC Inlet Enthalpy is by seller. ACC inlet enthalpy is the enthalpy the ACC can accept from the turbine, this may be different from the ACC design pressure. If so, extra equipment will be needed.

(8) Pump or Ejector is specified by buyer, Manufacturer and Model is by seller.

(9) Hogger Pressure and Time Requirement by buyer. If Pump then pump horsepower should replace minimum steam flow by seller.

(10) Pump or Ejector is specified by buyer. Manufacturer and Model is by seller.

(11) Holding Design Flow and Steam Requirement by seller. If Pump then pump horsepower should replace minimum steam flow by seller.

(12) By seller. kW should already be included in the total aux load guarantee.

	AIR-COOLED CONDENSER *PROJECT NAME*	Job No:	
		MR No:	
		Attachment	
		SHEET	2 OF 2

NONMANDATORY APPENDIX H
REPORTING FORM OF RESULTS OF ACC PERFORMANCE TEST

H-1 GENERAL INFORMATION (NUMBER OF READINGS)

(a) Name and Location of Plant ________
(b) Date etc. ________
(c) Number of test runs (min. 6 over 2 days) ________
(d) Duration of test runs (min. 1 hour) ________ hr ________ min
(e) Atmospheric pressure (start/end)
  (1) ________/________ kPa
  (2) ________/________ (in. HgA)
(f) Wind speed/Gusts (every minute)
  (1) ________/________ m/s
  (2) ________/________ (mph)
(g) Wind direction (every minute) ________
(h) Weather (start/end) ________/________

H-2 STEAM AND WATER CONDITIONS (NUMBER OF READINGS)

(a) Steam flow (every minute)
  (1) ________ kg/s
  (2) ________ (lb/hr)
(b) Steam temperature (every minute)
  (1) ________°C
  (2) ________ (°F)
(c) Steam pressure (every minute)
  (1) ________/________ kPa
  (2) ________/________(in. HgA)
(d) Condensate flow (every minute)
  (1) ________ kg/s
  (2) ________ (lb/hr)
(e) Condensate temperature (every minute)
  (1) ________ °C
  (2) ________ (°F)
(f) Makeup flow (every minute)
  (1) ________ kg/s
  (2) ________ (lb/hr)
(g) Makeup temperature (every minute)
  (1) ________ °C
  (2) ________ (°F)
(h) Dissolved oxygen (see Nonmandatory Appendix F)
  (1) ________ μg/L
  (2) ________ (ppb)

H-3 POWER AND AIR (NUMBER OF READINGS)

(a) Fan motor input power (once every test run) ________ kW
(b) Inlet air dry bulb temperature (every minute)
  (1) ________°C
  (2) ________ (°F)
(c) Plant output, kW ________
  (1) ________ gross
  (2) ________ net
(d) Heat rate
  (1) ________ kJ/kWh
  (2) ________ (Btu/kWh)

NONMANDATORY APPENDIX I PERFORMANCE MONITORING

I-1 INTRODUCTION

The main body of this Code is written for the purpose of acceptance testing and describes requirements for acceptance test measurements. This Appendix however addresses techniques that permit trending and ACC equipment performance evaluations during operation. Satisfactory performance monitoring can be achieved without the stringent instrument accuracy required for acceptance testing. That lack of necessity of an absolute numerical level of test results is what distinguishes the monitoring test plan focus, setup, and data from acceptance testing. Relative measurements and repeatability are critical. If the data prove to be repeatable during basically the same operating conditions, correction factors to absolute performance levels can always be developed from an analysis of those data sets.

Historical trending can be handled differently than acceptance testing because less emphasis is placed on the actual measurement accuracy. Although exact values are important, the differences that exist between them are of greater interest. Using the ACC pressure as an example, a 0.2 kPa (0.06 in. HgA) inaccuracy for a single measurement, although important for acceptance testing, makes little difference for multiple measurements since generally all values are biased in the same direction. Hence, ordinary operational sensors can be successfully used for trending purposes as long as their biases are considered and quantified. Accounting for differences in measurements can be accomplished by the installation of test quality sensors and comparing them to those permanently installed. Once the biases are determined, they can be used to correct the operational values. After the corrections have been incorporated, and the incremental changes in the pressure, for example, correspond to operational changes in the pressure of the ACC, the retrieved information can be used to start an historical file on the ACC performance parameters. The following discussion describes the considerations of the performance monitoring tests of air-cooled steam condensers.

I-2 PERFORMANCE MONITORING TEST STRUCTURE

Performance monitoring can range from periodic to real time on-line testing. Implementation of a performance monitoring program will vary significantly between plants and will be based on local needs, economics, and resources including the ACC performance, instrumentation methods, and methods of data collection and interpretation.

A decision that significantly characterizes an ACC monitoring program is whether to observe periodically, continuously, or both. The major benefits of continuous performance monitoring are

(a) the knowledge of when changes occur and what the related circumstances were in order to develop the earliest operational or maintenance response

(b) the ability to anticipate if there will be more severe changes from the initial indications

(c) the continuous assessment of how the ACC influences generation or the costs

Nonetheless, a compromise may be considered that balances the one time high capital costs and maintenance cost of the continuous system's permanent instrumentation against the repetitive setup costs and data collection of the periodic test. It should also be recognized that more complex and reliable levels of performance monitoring require increased quantities of instrumentation.

I-3 PARAMETERS TO MONITOR

The following parameters are recommended for monitoring, though the actual list is always dictated by the overall program's objectives:

(a) ambient local dry bulb temperature
(b) air inlet temperature
(c) ACC initial temperature difference
(d) turbine backpressure
(e) wind direction and approximate speed
(f) estimated recirculation
(g) fan power
(h) heat load
(i) air in-leakage
(j) condensate temperature
(k) condensate flow
(l) generation

I-4 MONITORING MEASUREMENTS

The Code requirements can be relaxed and adapted for performance monitoring as long as the sensors in question are still sufficiently precise to reliably reflect the same relative test value as conditions change. If a modern plant data collection system (DCS) is not available, a recorder with a computer interface is recommended. Computers with data logging capability can also be used. Manual readings using local instrumentation, although not recommended, are an alternative. A formal data sheet should be constructed so no readings are overlooked. Data sheets should be filled out on a periodic basis as recommended below to establish the necessary historical trending.

The performance monitoring variables are listed in Table I-4. With regard to steam exhaust pressure and air inlet temperature measurements, refer to sections of this Code or the supporting PTC 19 Series Codes for instrumentation choices. For example, air temperatures should be measured at the discharge of fan with instrument position governed by para. 4-3.6.

Some new instrumentation is likely a requirement for a successful monitoring program.

I-5 CALCULATIONS

Refer to Section 5 for the details of the computations of the parameters for trending. Depending on the scope and extent of the performance-monitoring program, the variables shown in the listing of section I-3 are recommended to be plotted with respect to time. This would include, e.g., condenser pressure, initial temperature differences (ITD), inlet air temperature, the apparent recirculation, wind speed, fan power, the condenser capability, gamma factor, condensate temperature, air inleakage, dissolved oxygen, and generation. Normalize the data with respect to design capability if applicable. Benchmark milestone operating and maintenance conditions such as washing the outside of the tube bundles, adjusting the fan blade pitch or finding major air leaks.

Data validity can be assured by examining the statistical data variation. The data should be precise, consistent, and dependable. Suitable approximations can also be made depending on the experience of the personnel and program goals.

Table I-4 Performance Monitoring Variables

Measurement	Code Requirement	Performance Monitoring Method	Potential Caveats and Inaccuracies
Turbine exhaust pressure (measure hourly)	Four measurements per exhaust duct	Two basket tip or guide plate measurements total or use of exhaust hood temperature	High steam velocity and water droplets may cause inaccuracy. Hood temperatures can be influenced by local temperatures and conduction effects; water in lines, vacuum leaks, long sensing lines, use of wall taps rather than basket tips; out of calibration or poor initial calibration.
Condensate (steam) flow (measure hourly)	Venturi meter, orifice meters, flow nozzles and time-of-travel ultrasonic meter	Pitot tube centerpoint, annubar, pump total dynamic head (TDH) and curve, heat balance method	Nonrepresentative velocity profile or large vorticity at location of meter due to short straight runs; out of round pipe diameter; ongoing condensate pump deterioration; inaccurate gauge or correction to pump C/L; out of calibration transducers.
Generation (measure hourly)	Not necessary	Use control room data-watt-hr meter; net or gross	Usually accurate.
Condensate temperature (measure daily)	Per ASME PTC 19.3	Use thermowell of at least one-third the pipe diameter and insulate from pipe conduction effects	Pipe conduction effects, no fluid in thermowell, emergent stem if thermometer, poor calibrations.
Ambient air (dry bulb) temperature (measure hourly)	Meteorological station at plant	Same as Code if possible or local airport	Distance between measurement and steam condenser itself. Local plant influences.
Inlet air temperatures (measure hourly)	Twelve per unit with one at each fan walkway	Walkway temperature measurements at three to five key, representative fans	Influenced by changing recirculation, widely varying wind speeds and directions and size of unit.
Wind speed (measure hourly)	Remote reading meteorological anemometer at plant	Same as Code if possible or local airport	Local influence of terrain, power complex buildings and ground; poor instrument quality; effect of weather and time on basic meter correlation.
Fan power (measure daily)	Local wattmeters or motor voltage and amperage	Same as Code but remotely recorded	Poor inherent instrument quality; changing motor efficiencies; poor calibration.
Air inleakage (measure weekly)	Orifice or rotometer	Orifice or rotometer or manually (like Bag method)	Transducer out of calibration; blockage.
Dissolved oxygen (measure weekly)	O_2 analyzers (Appendix F of Code)	O_2 analyzers per Code	. . .

NONMANDATORY APPENDIX J
ROUTINE PERFORMANCE TEST

J-1 OBJECTIVE

The Routine Performance Test is intended to provide an analytical basis for comparison of the current performance of an ACC with its design or like-new condition.

J-2 GUIDING PRINCIPLES

The Routine Performance Test should follow the requirements of the Acceptance Test, except for the following:

(a) It will normally be a single-party test, rather than a multiparty test.

(b) Plant permanent instruments and data-recording system may be used, even if they do not meet the accuracy requirements for the Acceptance Test.

(c) Only one test run is required, rather than a minimum of six. (However, additional test runs may be made if convenient.)

(d) Uncertainty analysis is not required.

J-3 INSTRUMENTS AND METHODS

J-3.1 Inlet Air Temperature

This parameter has the greatest effect on uncertainty of the test results (see Nonmandatory Appendix B). Every effort should be made to determine the most accurate average temperature that the ACC is experiencing throughout its intake area. Therefore, the requirements of para. 4-3.6 shall be observed if practical. All temperature sensors should be in operation and have been calibrated within one year.

Temperatures shall be recorded at one-minute intervals as required in para. 3-8.5.3. If this is not practical for the instruments used, temperatures shall be recorded at intervals of one hour or less.

J-3.2 ACC Pressure

This parameter also has a great effect on uncertainty of test results. All basket tips or guide plates should be in place and all pressure sensors should be in operation, within calibration, and clear of accumulated condensate.

NONMANDATORY APPENDIX K
ENVIRONMENTAL EFFECTS

K-1 OBJECTIVES

This Appendix provides a level of guidance on the way the environment influences the performance of the air-cooled condenser (ACC). These environmental effects are many and can often be significant including

(a) a varying recirculation at different wind speeds

(b) fan stall or unloading

(c) nonrepresentative inlet or ambient temperatures

(d) poor inherent performance in local wind due to speed or direction compared to the Code wind speed limits

(e) Code test results that would not be representative of daily operation

All these impacts on the performance can be estimated by a computational fluid dynamic (CFD) simulation study of the ACC. The simulation would be better conducted during the design phase of the power plant but may also be accomplished later. In particular, it should be appreciated that the results of such a study would provide an estimate of the relationship of test results according to this Code and the expected daily operation at the site with its local topography and the existing environmental conditions. When conducted at the design stage, the study would provide a reasonable engineering perspective on the expected results and can provide insights as to how the design arrangement can be improved to be more accommodating of the local environmental impacts. When CFD studies are conducted before the plant operates but after the ACC design arrangement is established, the simulation can determine the minimal number of temperature sensors that can be utilized in a performance-monitoring program. The CFD study can also aid the Code acceptance test plan itself and indicate what measurement inaccuracies may be encountered or the modified wind conditions or instrument locations that could enhance the overall test accuracy.

CFD modeling involves the solution of the fundamental equations of fluid motion using numerical, computerized techniques. Using a computer, the region of interest is divided into numerous small volumes, or cells, and equations for each of the chosen variables are solved for each cell. As a result, an assessment of velocity and scalar variables, such as temperature within the calculation domain, are obtained. Powerful graphics permit the basis or computed variables to be comprehensively displayed.

The general approach is to incorporate the dimensions of the required geometry into the CFD model. This is implemented in two stages, the first being a coarse division of the domain into smaller regions. These regions are then individually meshed using grid lines that subdivide the regions into grid cells. The individual regions are then "glued" together by the computer to form the whole geometry. Partial differential equations, governing fluid flow, heat transfer, etc., are then solved for each grid cell. The resulting sets of partial differential equations are solved for each parameter of interest, namely the velocities in the coordinate directions (u, v, w), pressure (p), temperature (T), turbulence kinetic energy (k) and its dissipation rate (ε), and other scalar variables.

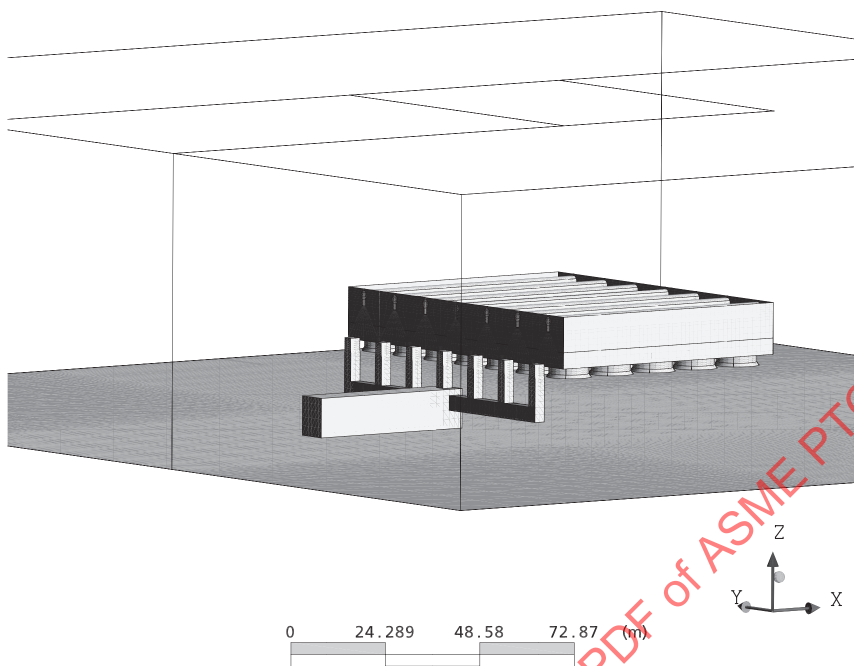
A typical CFD model study follows. This CFD model was developed for a particular ACC unit's geometry and design conditions but serves as an example of quantifying the wind effects by applying both a zero wind and wind speeds up to 5 m/s. The unit modeled has 35 cells in a 5 × 7 array. Figure K-1-1 gives an overall view and shows the wind walls, the steam ducts leading from the turbine, and some external structure.

Each fan is represented. The casing is defined as a surface, as shown in the lower part of Fig. K-1-2, and the grid above the fans is structured to enable a representation of the geometry of the heat-exchanger tubes and steam pipes. Figure K-1-2 shows a geometrical representation of these features. Above the fans, the grid slopes up to the steam pipes, following the geometry of the tubed region. Surfaces above the fans and connecting the bottom of the tubed regions have been inserted, so that air can only flow through the tube banks.

The energy supplied by the fan is represented as a momentum source incorporated within each fan volume. In the calculations performed, these momentum sources are equal in each fan and are based on the manufacturer's data on design flow rate. The friction across the tube bank and heat transfer from steam to air is also included.

The calculations performed with the model are presented to give a general appreciation of the effects of wind. The overall flow behavior is affected by the particular geometry considered, hence, for example, the influence of porous baffles that are use to offset the effects of wind are not considered. The results are presented in the form of flow visualization plots and graphs of velocity and pressure effects. The effect on the fan performance is also tabled, and an estimate of the decrease in performance due to wind is presented.

Fig. K-1-1 Perspective View of Model



K-2 WIND EFFECTS

Results are presented for two types of cases, a "no-wind" case, where all the atmospheric boundaries are taken as constant pressure boundaries and the only sources of momentum are the fans. In the wind cases, a 5.0 m/s wind is established from the west, the same momentum sources are used in the fans, and pressure boundaries are specified elsewhere.

Figures K-2-1, K-2-2, and K-2-3 show plots of velocity vectors, pressure and temperature contours for the zero wind case. The velocity distribution though each fan is broadly similar.

Figure K-2-2 illustrates the pressure distribution in this area—a low pressure below the fan inlet, and higher pressure due to the resistance of the tube bundle.

Figure K-2-3 illustrates the temperature field, heat being transferred to the air via the tubes.

Figure K-2-4 shows a larger view of the velocity field, indicating the effect that the wind wall has in modifying the fan inlet flow distribution.

Figure K-2-5, illustrations (a) and (b) show the plane just below the fan inlet and compares the no-wind and wind cases, the wind direction is from the left in illustration (b). It can be seen that the velocity fields below the fan inlets are dissimilar.

Temperature fields with and without wind are compared in Fig. K-2-6, illustrations (a) and (b). A high temperature region on the fan at the windward end of the condenser is noticeable.

Figure K-2-7 compares the velocity distributions just below the fan inlets for zero and 5 m/s wind. The peak velocities in the graphs correspond to the centers of the fan casings. It can be seen that with no wind the distributions are fairly similar, but that wind has the effect of reducing the velocities in the fans at the edges of the unit.

Figure K-2-8 shows similar plots of pressure variation below the fan inlets. With no wind, a lower pressure is observed in the fans adjacent to the wind walls, but uniform in the three center fans. With a 5 m/s wind the pressure is lower below the windward fan, increasing toward downwind side.

Tables K-2-1 and K-2-2 show normalized mass flow rates through each fan for the no-wind and a wind of 5 m/s. The wind case shows a significantly larger variation of flow, the lowest values occurring on the windward side. In addition, the overall mass flow through the unit is reduced by 22% as a result of a 5 m/s wind.

Based on the decreased mass flow through the unit, the increase in condenser backpressure could increase from about 10 kPa to 15 kPa.

In this case, the loss in performance would vary with the particular ACC geometry, wind speed, and direction. It could have been mitigated to some extent by changes in the design, wind-wall baffling or arrangement of the ACC. The location of building close to the unit can also have a marked influence on the flow behavior and subsequent performance.