

ASME PTC 12.2-2010
[Revision of PTC 12.2-1998 (R2007)]

Steam Surface Condensers

Performance Test Codes

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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.

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FOREWORD

When the work of revising the ASME Power Test Codes of 1915 was undertaken, it was decided to include a committee to develop three separate test codes on condensing apparatus, feedwater heaters, and water-cooling equipment. The resulting Test Code for Steam-Condensing Apparatus, after passing through the preliminary stages in the procedure prescribed by the Main Committee, was printed in tentative form in the May 1924 issue of *Mechanical Engineering* and was presented to the Society for discussion at a public hearing held during the spring meeting in Cleveland in May 1924. At the December 1924 meeting of the PTC Supervisory Committee (now known as the Board on Performance Codes), it was approved in its final revised form, and on October 5, 1925, it was approved and adopted by the Council as a standard practice of the Society.

Early in 1933, Committee No. 12 decided to completely revise the Test Code for Steam-Condensing Apparatus. At the April 4, 1938, meeting of the PTC Supervisory Committee, this second version of the Code was approved, and on July 15, 1938, it superseded the previous one and was adopted by the Council as a standard practice of the Society.

With the reorganization of PTC Committee No. 12 on Condensers, Feedwater Heaters, and Deaerators in 1948, the main Power Test Codes Committee requested that the Test Code for Steam-Condensing Apparatus be updated. This third edition of the Code was approved at the December 4, 1953, meeting of the Power Test Codes Committee and adopted by the Council as a standard practice of the Society on March 9, 1954.

In January 1970, the PTC Supervisory Committee requested the Test Code for Steam-Condensing Apparatus be reviewed and updated. That fourth version of the Code was approved by the Board on Performance Test Codes on May 7, 1981, and it became an American National Standard in January 1983.

The Board on Performance Test Codes in 1988 directed the Code again be reviewed to ensure it reflected current engineering practices. A new Code Committee was organized in early 1989 containing members from a wide geographical area. It comprised about equal numbers of manufacturing, user, and general interest members to ensure balanced Committee actions. The 1989 Committee was organized into four subcommittees—Guiding Principles, Test Procedures, Instruments and Methods, and Computation of Results—to ensure each section of the Code revision would be properly addressed and the work would be accomplished effectively.

Based on experience with the two previous versions of the Condenser Code, the reorganized Committee determined to make this Code modern, accurate, practical, useful, and cost-effective. It also identified the objective of extending the Code to include performance monitoring, because of the relatively large effect of operating condensers on plant generation and efficiency.

These ambitious goals translated into extensive revisions that triggered an almost complete rewrite. The major areas were revised, and the rationale for the 1998 revision of this Code was as follows:

- (a) *Instruments*. To take advantage of the then-significant advances in the field, instrumentation recommendations were modernized.
- (b) *Heat Transfer*. To enlarge the schedule “window” for the condenser test while maintaining accurate test results, the separate heat-transfer resistance method with the latest correlations was adopted.
- (c) *Implementation*. To clarify the Code rules and produce a virtually self-contained document, techniques and instrumentation descriptions were written in an explicit and detailed manner.
- (d) *Uncertainty Determinations*. To ensure proper applications of uncertainty analysis, all the particulars of this somewhat daunting estimate (a very important and now necessary aspect of every test) were presented.
- (e) *Data Acquisition*. To improve the condenser test effectiveness, computerized data acquisition for the testing and data reduction was recommended; however, the Code was written so that this approach was not necessary.
- (f) *Cleanliness Testing*. To be certain the condenser performance results were not predestined, a mandatory cleanliness test was required by the 1998 edition of the Code. It is important to note, though, that the previous cleanliness test section was replaced in its entirety with a new, pragmatic fouling test procedure.

Last, the expanded fifth edition of the Code was retitled *Steam Surface Condensers*. This Code was approved by the PTC 12.2 Committee on January 20, 1996. It was then approved and adopted by the Council as a standard practice of the Society by action of the Board on Performance Test Codes (BPTC) on December 20, 1996. This Performance Test Code was also approved as an American National Standard by the ANSI Board of Standards Review on February 20, 1998.

The 1998 Condenser Test Code was mainly focused on conducting a rigorous, full-scale acceptance test. After several years of experience with that Code, it was reported that its use was infrequent because of the complicated and expensive requirements of a full-scale condenser performance test. The PTC 12.2 Committee was reconstituted on June 14, 2007, to undertake a revision of the Code. The Committee decided that the revision would include a less rigorous test that would

also be considered as an acceptance test. The rationale was to better establish equipment-performance metrics with the philosophy of promoting testing. This less-accurate test provides a slight relaxation of the allowable test conditions and requirements. The revision includes an update of the condenser test technology.

This, the sixth edition of the Code, was approved by the PTC Standards Committee on November 2, 2009, and approved and adopted as a standard practice of the Society by action of the Board on Standardization and Testing on December 8, 2009. The Performance Test Code was also approved as an American National Standard by the ANSI Board of Standards Review on January 14, 2010.

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Performance Test Codes

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Secretary, PTC Standards Committee
The American Society of Mechanical Engineers
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New York, NY 10016-5990
<http://go.asme.org/inquiry>

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.

Request for cases shall provide a Statement of Need and background information. The request should identify the Code, 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 of the Code to which the proposed Case applies.

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

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

- Subject:** Cite the applicable paragraph number(s) and a concise description.
- 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. ASME does not "approve," "certify," "rate," or "endorse" any item, construction, proprietary device, or activity.

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

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STEAM SURFACE CONDENSERS

Introduction

This Code describes instruments, test procedures, and methods of test-data analysis to be used to determine and monitor the performance of steam surface condensers. It provides explicit test procedures that will yield results of the highest level of accuracy consistent with the best current engineering practices and knowledge in this field. The Code is not intended to be used for tests of condensers or heat exchangers operating above atmospheric pressure or air-cooled condensers.

To aid in an overall study of the Code, the following review sequences are recommended:

(a) A quick survey of the Code can be obtained by reading the introductions to each Section followed by the test procedures flowcharts in subsection 4-9 and Nonmandatory Appendices B, G, and H, and the Test Plan Checklist in Nonmandatory Appendix B.

(b) At the plant design, contractual agreement, or specification stage, it is advisable to review in order the following:

- (1) achievable test uncertainty as stated in subsection 1-3
- (2) test procedures, or alternatively the particular special test from Nonmandatory Appendix A
- (3) test plan and flowcharts
- (4) guiding principles (see Section 3)
- (5) instrumentation and methods of measurement to determine the hardware that must exist or be installed

in the condenser to determine the recommended measurements (see Section 4)

(c) Those interested in performance monitoring should review Nonmandatory Appendix C, then the test plan and flowcharts before reviewing Code Section details.

When this Code is to be used to determine fulfillment of contractual obligations, the contracting parties shall agree in advance on the test procedures, uncertainty estimates and implications, and methods of presentation of data and presentation of results.

Considerable efforts were made to write this condenser Code so that all the related technology would be contained within the document itself; however, this was not possible in all instances. In these cases and unless otherwise specified, all references to other codes refer to ASME Performance Test Codes. Any terms not defined herein are listed in ASME PTC 2, *Definitions and Values* [1]. Descriptions of instruments, apparatus, and the general basis of the uncertainty analysis beyond that specified in this Code may be found in the Supplements on Instruments and Apparatus, ASME PTC 19.1 [1]. A careful study should be made of all the referenced codes, but in the event of discrepancies between the specific directions contained herein and those Codes incorporated by reference, ASME PTC 12.2 shall govern.

Section 1

Object and Scope

1-1 OBJECT

This Code provides standard directions and rules for conducting and reporting performance tests of water-cooled, steam surface condensers, hereafter referred to as condensers. This Code provides explicit test procedures for performing a reasonably accurate, pragmatic level of performance testing.

If higher levels of accuracy are desired, the alternative test, described in Nonmandatory Appendix A, can be performed in lieu of the test.

Acceptance testing is used to determine compliance with contractual obligations and can be incorporated into commercial agreements. The test shall be considered an ASME Code test only if the test procedures comply with this Code.

1-1.1 Performance Parameters

This Code provides rules for determining the following condenser performance parameters:

- (a) the absolute pressure maintained by the condenser
- (b) the test pressure of the condenser corrected to the design-reference conditions
- (c) the extent of condensate subcooling
- (d) the amount of dissolved oxygen in the condensate
- (e) the tubeside pressure drop

1-1.2 Test Methods

Test methods for determining the condenser performance and degree of tube fouling, expressed as a cleanliness factor and fouling resistance, are described for both tests.

1-2 SCOPE

The rules and instructions included in this Code are for the condenser. The test does not assess the per-

formance of any of the auxiliary apparatus associated with the condenser. For any related equipment components, refer to other ASME Performance Test Codes.

1-3 UNCERTAINTY

The test results shall be considered the direct evidence of the condenser's performance. These test results shall not be adjusted by the test uncertainty.

(a) The uncertainty for this performance test has been predetermined for typical instrumentation as recommended in Section 4. Using the recommended instrumentation, the test uncertainties of the following parameters are expected to be no greater than those listed below:

- (1) absolute pressure maintained by the condenser, ± 0.17 kPa (± 0.05 in. HgA)
- (2) the test pressure adjusted to the design or reference point, ± 0.51 kPa (± 0.15 in. Hg)
- (3) condensate subcooling, $\pm 0.11^\circ\text{C}$ ($\pm 0.2^\circ\text{F}$)
- (4) dissolved oxygen in the condensate, ± 4.0 $\mu\text{g/L}$ (± 4.0 ppb)
- (5) tubeside pressure drop, $\pm 9\%$

(b) The typical expected uncertainties of performing the alternative test, as described in Nonmandatory Appendix A, are as follows:

- (1) absolute pressure maintained by the condenser, ± 0.14 kPa (± 0.04 in. HgA)
- (2) the test pressure adjusted to the design or reference point, ± 0.41 kPa (± 0.12 in. Hg)
- (3) condensate subcooling, $\pm 0.11^\circ\text{C}$ ($\pm 0.2^\circ\text{F}$)
- (4) dissolved oxygen in the condensate, ± 4.0 $\mu\text{g/L}$ (± 4.0 ppb)
- (5) tubeside pressure drop, $\pm 9\%$

Section 2

Definitions and Descriptions of Terms

2-1 SYMBOLS

The symbols in Table 2-1-1 are used unless otherwise defined in the text.

2-2 SUBSCRIPTS

The following subscripts are used unless otherwise defined in the text:

Symbol	Term
<i>B</i>	Bulk
<i>c</i>	Clean
<i>DO</i>	Dissolved oxygen
<i>F</i>	Film
<i>f</i>	Fouling factor
<i>G</i>	Gas (noncondensable)
<i>i</i>	Inside tube
<i>m</i>	Metal
<i>o</i>	Outside tube
<i>s</i>	Shell or steam
<i>sat</i>	Saturation
<i>t</i>	Tubeside

<i>V</i>	Vapor
<i>w</i>	Wall of tube
<i>x</i>	Low-pressure section
<i>y</i>	Intermediate-pressure section
<i>z</i>	High-pressure section
1	Inlet
2	Outlet
3	Condensate
Δ	Differential

2-3 SUPERSCRIPTS

The following superscripts are used unless otherwise defined in the text:

Symbol	Description
*	Value derived from the design reference
+	Measured value or calculated value at the test conditions
o	Test value corrected to the design-reference conditions

Table 2-1-1 Symbols

Symbol	Term	Description	Units	
			U.S. Customary	SI
<i>A</i>	Effective outside-tube surface area	Total active external area of all tubes in condenser, including external air cooler if used. Active area excludes any tubes that may be plugged at time of test.	ft ²	m ²
<i>c_f</i>	Cleanliness factor	Ratio of thermal transmittance of tubes to that of new or cleaned (to a like-new state) tubes operating under identical conditions	...	...
<i>c_p</i>	Specific heat	Specific heat of cooling water at average temperature and for salinity measured during test	Btu/lb•°F	J/gK
<i>D</i>	Tube diameter	Diameter of condenser tube	...	m
<i>DO</i>	Dissolved oxygen	Amount of oxygen dissolved in condensate	ppb	µg/L
<i>d</i>	Tube diameter	Diameter of condenser tube	in.	...
<i>F</i>	Fluorescence	Measure of the presence of an indicating dye in percent of solution for use in determining flow rate in large conduits (percent)	...	...

Table 2-1-1 Symbols (Cont'd)

Symbol	Term	Description	Units	
			U.S. Customary	SI
g	Acceleration of gravity	Constant used in Nusselt equation	ft/sec ²	m/s ²
h	Heat-transfer coefficient	Rate of heat transfer per unit of surface area and temperature difference	Btu/hr · ft ² · °F	W/m ² · K
j	Variable	Summation	...	...
k	Thermal conductivity	Rate of heat transfer per unit of distance within a material (with values as listed in a recognized standard)	Btu/hr · ft · °F	W/m · K
L	Length	Condenser tube length	ft	m
$LMTD$	Log mean temperature difference	Computed logarithmic mean temperature difference between steam and cooling water (see Section 5)	°F	°C
\ln	Natural logarithm		...	...
m	Molecular weight	Formula mass	lb/lb-mol	kg/kg-mol
N	Quantity	Number of condenser tubes	...	...
NTU	Number of heat-transfer units		...	...
n	Quantity	Number of condenser tubes passes	...	...
P	Pressure	Absolute fluid pressure	in. HgA	kPa
Pr	Prandtl number	Ratio of momentum diffusivity to thermal diffusivity ($c_p \mu / k$)	...	...
Q	Condenser heat load	Rate at which heat in steam is transferred to cooling water. This is usually considered the independent variable in any condenser test.	Btu/hr	W
R	Resistance	Heat-transfer resistance	hr · ft ² · °F/Btu	m ² K/W
Re	Reynolds number	Ratio of inertial reaction per unit volume of fluid to viscous force per unit volume of fluid ($\rho d v / \mu$)	...	...
$SCFM$	Air in-leakage	Measured rate of standard air in-leakage into condenser at 1 atm (14.7 psia) and 15.56°C (60°F) as discharged from the air-removal system	scfm	slpm
T	Temperature	Temperature of cooling water, steam, or condensate	°F	°C
ΔT	Temperature differential	Difference in fluid temperature between two points	°F	°C
U	Overall heat-transfer coefficient	Rate of heat transfer per unit of surface area and temperature difference. This quantity is the fundamental measure of the condenser performance.	Btu/hr · ft ² · °F	W/m ² K
v	Cooling-water velocity	Average water velocity through tubes. For multipass condensers with an unequal number of tubes in the different passes, the average of the average velocities for all passes shall be used.	ft/sec	m/s
w	Flow rate	Quantity of cooling water passing through condenser per unit of time	lb/hr	kg/h
Ws	Steam flow rate	Quantity of steam entering condenser per unit of time	lb/hr	kg/h
Δ	Differential	Difference between two measured values	...	...
ΔH	Differential pressure	Differential pressure across the orifice plate in a water gauge	in.	cm
ΔP	Pressure drop	Loss of pressure due to friction in fluid system between two points	psi	kPa
μ	Viscosity	Intensity of viscous shear within a fluid	lb · hr · ft	kg/s · m
ρ	Density	Ratio of mass to volume of a fluid or solid	lb/ft ³	kg/m ³

Section 3

Guiding Principles

3-1 PURPOSE AND INTENT

This test is designed to measure condenser performance and associated parameters. For acceptance testing, a test plan should be created following the guidelines given in this Section. Nonmandatory Appendix B contains flowcharts and checklists for creating a test plan.

3-2 AGREEMENT BETWEEN PARTIES TO THE TEST

For multiparty tests, agreement shall be reached on the specific objectives of the test and the method of operation. The agreement shall reflect the intent of any applicable contract or specification. Any specified or contractual operating conditions, or any specified performance that is pertinent to the objective of the test, shall be ascertained. The arrangement and operating conditions of pertinent equipment and systems shall be established during the agreement on test methods.

3-3 TEST CONSIDERATIONS

The following typical issues should be considered in the system and equipment design, as they would impact the test:

- (a) objective of the test (e.g., absolute pressure, design pressure, subcooling, dissolved oxygen, tubeside pressure drop, tube-bundle performance, cleanliness factor, fouling resistance)
- (b) test boundaries
- (c) the timing of the test
- (d) operating conditions
- (e) guarantees
- (f) treatment of anticipated deviations from the requirements of this Code
- (g) means of determining overall heat-transfer coefficient
- (h) means for determining condenser shellside pressure
- (i) means for determining cooling-water temperatures
- (j) means for determining cooling-water flow
- (k) means for determining condenser fouling
- (l) means for determining dissolved oxygen in the condensate
- (m) means for determining condensate subcooling
- (n) means for determining cooling-water pressure drop

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

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

(q) whether the testing is to be performed on each piece of equipment separately or on the system as a whole

3-4 PRETEST AGREEMENTS

The following is a list of typical items upon which agreement shall be reached prior to conducting the test and which shall be 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.
- (e) method of diverting or measuring drain makeup water and other incoming flows.
- (f) means for verification that allowable noncondensibles are within limits of Table 3-4-1.
- (g) method for confirming condensate dissolved oxygen (e.g., plant instrumentation, external lab tests).
- (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, steam extraction 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 procedures and factors to adjust test conditions to specified conditions, per Table 3-4-2.
- (q) method of determining any corrections not otherwise addressed by this Code.

Table 3-4-1 Noncondensable Gas Load (Air In-Leakage Limits)

SI Units		
Number of Shells	Total Exhaust Steam Flow, kg/hr	Noncondensable Gas Load Limit [per unit], slpm
1	Up to 113 378.7	85
1	113 378.7–226 757.4	113
1	226 757.4–453 514.7	142
1	453 514.7–907 029.5	170
1	907 029.5–1 360 544.2	198
1	1 360 544.2–1 814 059	226
2	90 703–226 757.4	142
2	226 757.4–453 514.7	170
2	453 514.7–907 029.5	255
2	907 029.5–1 814 059	311
2	1 814 059–2 721 088.4	368
2	2 721 088.4–3 628 117.9	425
3	340 136.1–1 360 544.2	311
3	1 360 544.2–3 628 117.9	396
3	3 628 117.9–4 081 632.7	482
3	4 081 632.7–5 442 176.9	566

U.S. Customary Units		
Number of Shells	Total Exhaust Steam Flow, lb/hr	Noncondensable Gas Load Limit [per unit], scfm
1	Up to 250,000	3.0
1	250,000–500,000	4.0
1	500,000–1,000,000	5.0
1	1,000,000–2,000,000	6.0
1	2,000,000–3,000,000	7.0
1	3,000,000–4,000,000	8.0
2	200,000–500,000	5.0
2	500,000–1,000,000	6.0
2	1,000,000–2,000,000	9.0
2	2,000,000–4,000,000	11.0
2	4,000,000–6,000,000	13.0
2	6,000,000–8,000,000	15.0
3	750,000–3,000,000	11.0
3	3,000,000–6,000,000	14.0
3	6,000,000–9,000,000	17.0
3	9,000,000–12,000,000	20.0

Table 3-4-2 Allowable Deviations From Specified Test and Steady-State Conditions

Testing Parameter	Deviation Limit From Specified Test Conditions	Constancy of Conditions
Inlet cooling-water temperature	$\pm 6^{\circ}\text{C}$ (10.8°F)	$\pm 1^{\circ}\text{C}$ (1.8°F)
Heat load	$\pm 5\%$	$\pm 2\%$
Cooling-water flow	$\pm 5\%$	$\pm 2\%$

(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 receive process steam.

(s) method of determining adjusted test results.

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

(u) test report distribution.

(v) acceptance criteria for tubeside blockage and tubeside fouling.

3-5 ALLOWABLE DEVIATIONS

Testing shall be performed under conditions of constant inlet-water temperature, heat load, and cooling-water flow within the limits specified in Table 3-4-2. Performance degradation that is not inherent to the design or the fabrication of the condenser should be noted, such as tube fouling, pluggage, sleeving, and tube-sheet blockage. Similarly, abnormal operation or internal items such as failure of lines, connections, or spargers to operate as designed within the steam space should also be noted.

3-6 PREPARATION FOR TEST

Prior to the test, the parties to the test shall be given an opportunity to examine and familiarize themselves with all the apparatus connected with the condenser, and all piping. The selected instruments and their calibration shall also be agreed upon in advance of the test. Instrument readings should be taken prior to the test to ensure all instruments are suitably connected and operating properly.

3-7 CONDENSER ISOLATION

As required, a method of diverting or measuring drains shall be agreed upon prior to testing. Any pertinent drains or dumps that can jeopardize the results of the test shall be isolated. This includes makeup water that can affect dissolved-oxygen concentration discussed in subsection 3-11.

3-8 NONCONDENSIBLE GAS LOAD

Excessive air in-leakage often degrades the condenser performance and increases the concentration of dissolved oxygen in the condensate. Since the air in-leakage directly impacts the condenser heat-transfer capability,

it must be within the limits set in Table 3-4-1. This will ensure that the performance of the condenser has not been impaired prior to the test. The noncondensable gas load shall be measured to assure adherence to the guidelines in Table 3-4-1. Techniques for measuring noncondensable gas load are given in ASME PTC 19.5 [1]. It is important to verify that all air-removal equipment is functioning properly prior to the performance test.

NOTE: For single- or two-shell units with large total exhaust steam flow, refer to Table 3-4-1 values for three shells and the corresponding total exhaust flow in service.

3-9 TUBESIDE BLOCKAGE

The accumulation of debris on the inlet tube sheet is common in surface condensers and may even occur when the cooling water is carefully screened. Such accumulation results in totally or partially blocked flow to some tubes, thereby reducing the active surface area of the condenser. It is highly recommended that differential pressure measurement be employed throughout testing.

3-10 TUBESIDE FOULING

All condenser tubes shall be thoroughly cleaned just prior to the test. See Section 4 for the methods of determining the quantitative effect of tubeside fouling.

3-11 DISSOLVED OXYGEN

For a dissolved-oxygen concentration of 14 $\mu\text{g/L}$ (ppb), the total water introduced into the condenser shell at a temperature lower than the inlet-steam temperature shall not be more than 5% of the steam being condensed or more than 3% for a 7 $\mu\text{g/L}$ (ppb) dissolved-oxygen concentration.

When testing to determine compliance with the specified dissolved-oxygen concentration [para. 1-1.1(d)], the air in-leakage rates shown in Table 3-4-2 are not applicable. The air in-leakage rates shown in Table A-1-1 of Nonmandatory Appendix A shall be used.

Special considerations apply when testing systems where excessive makeup is introduced or where higher levels of dissolved oxygen are required for the condenser design. The dissolved-oxygen concentration in the condensate of such systems can be unstable and difficult to measure.

3-12 PRELIMINARY TESTING

Prior to performing the first test run, a preliminary test shall be conducted for the purpose of

- (a) determining whether all components are in suitable condition to conduct the test
- (b) determining whether all components have been properly isolated
- (c) checking all instruments for proper operation and accuracy
- (d) determining whether the methods of measurement conform to subsection 4-3
- (e) determining whether all testing parameters conform to Tables 3-4-1 and 3-4-2
- (f) adjusting the test plan as required
- (g) training of personnel who are performing the test

Parties to the test should 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 a preliminary test run complies with all the necessary requirements of this Code, it may be used as an official test run.

3-13 TEST RECORDS

3-13.1 Test Readings

To the extent possible, test readings shall be recorded on a data acquisition system. A complete set of test data shall become the property of each party to the test at the end of the test.

Upon completion of the test, the test data shall be reviewed to determine if any data should be rejected prior to calculation of the test results. If inconsistencies are observed in instrument readings during any test period, the data collected from that period shall be rejected, or it may be invalidated only in part if the affected part is at the beginning or end of the test run.

3-13.2 Reporting of Results

In all cases, the test results shall be reported

- (a) as calculated from the test readings recorded during the test, with only instrument calibration adjustments having been applied
- (b) as adjusted for deviations of the test conditions from the specified design conditions

3-14 DURATION OF TEST RUNS

After steady-state conditions are achieved, a 1-hr data collection period is sufficient for a single test run. Readings shall be taken at intervals not exceeding 5 min. For a 1-hr test, a minimum of 13 test readings for each parameter shall be taken.

3-15 DETERMINING THE OVERALL HEAT-TRANSFER COEFFICIENT, U

3-15.1 General Considerations

The main purpose of the test is to provide uniform guidelines to obtain an accurate overall heat-transfer coefficient, U , at the test condition. For an acceptance test, once U is adjusted to the specified point, the absolute pressure of the condenser at the specified point can be established.

The results from the test shall be corrected to specified conditions using the procedures described in Section 5. These correlations determine the ability of the unit to condense the required amount of steam and to maintain the nominal condenser pressure at test conditions adjusted to the specified design, or guarantee point. For a Code test, these corrections shall be applied properly.

Determining any two of the three following test parameters allows calculation of the third:

- (a) cooling-water flow
- (b) condenser temperature rise
- (c) condenser heat load

This would meet the requirements necessary to perform a complete equipment heat balance and ultimately serve as the foundation for calculating U . The corrections described in Section 5 are based on the governing heat-transfer mechanisms, using a log mean temperature difference (LMTD) approach to determine the overall U .

3-15.2 Measurements

To obtain an accurate U , the condenser shellside pressure, cooling-water inlet and outlet temperatures, and cooling-water flow shall be measured.

3-15.2.1 Condenser Shellside Pressure. The condenser shellside pressure is the main basis for the design or guarantee point. Condenser pressure is therefore a key measurement. The shellside saturation temperature, used in determination of U , is determined from the condenser shellside pressure. Acceptable instrumentation for the measurement of condenser pressure is described in subsection 4-3.

3-15.2.2 Cooling-Water Inlet and Outlet Temperatures. Inlet and outlet cooling-water temperatures are used to determine the U of the condenser. Since inlet cooling-water temperature is also specified in the design or guarantee conditions for the condenser, it is important that the inlet cooling-water temperature during the tests be within the guidelines specified in Section 3 and Section 4. Because outlet temperature stratification often occurs in condensers, particular attention shall be paid to the determination of outlet temperature. Careful consideration of the requirements of subsection 4-4 and the physical characteristics of the condenser installation should

precede any decision on the best means and location for measuring the outlet temperature.

3-15.2.3 Cooling-Water Flow. Unless a turbine test per ASME PTC 6 [1] is performed concurrently, direct measurement of the cooling-water flow rate, together with the inlet and outlet temperatures, is the preferred method of determining the heat load on the condenser, which is required to determine U . Several methods for accurately determining the cooling-water flow rate are given in subsection 4-5. Choice of an appropriate method shall be made only after considering both the requirements of the individual method and the characteristics of the particular installation.

It is extremely important that an appropriate method of cooling-water flow measurement is chosen. The heat load may also be determined by a full steam-cycle energy balance, performed in conjunction with a full turbine test as specified by ASME PTC 6 [1]. In this case, the cooling-water flow rate is not required for the determination of heat load.

3-16 AUXILIARY PARAMETERS

There are three auxiliary tests described by this Code:

- (a) a dissolved-oxygen test
- (b) a condensate subcooling test
- (c) a condenser hydraulic-pressure-drop test

Data should be collected coincident with the heat-transfer test of this Code, or separate tests. Other auxiliary tests such as air binding of noncondensable removal equipment may also be useful for diagnostic testing and are given in Nonmandatory Appendices G and H.

3-16.1 Dissolved Oxygen

The dissolved-oxygen concentration in the condensate is often a guarantee item for the acceptance of a condenser.

The test method for determination of dissolved oxygen is given in subsection 4-11. The test for dissolved oxygen should be conducted at the same time as the condenser tests, to ensure that all operating requirements are met.

It is especially important that the air-removal equipment be operating properly and that air in-leakage be held to acceptable limits during the tests. Noncondensable gas load is discussed in subsection 3-11. Further guidance on the assessment of the operation of the air-removal equipment can be found in Nonmandatory Appendix H.

3-16.2 Condensate Subcooling

Condensate subcooling (condensate depression) is the degree to which the condensate has been cooled below the saturation temperature corresponding to the measured condenser shellside pressure. Condensate subcooling shall be measured if it is a design or guarantee point for the condenser, or if it is of interest for general performance calculations. The condensate temperature shall be determined at the same time as the heat-transfer test, using the method given in subsection 4-12.

3-16.3 Cooling-Water Pressure Drop

The pressure drop across the condenser shall be adjusted from actual to design flow and should be equal to or less than the design values. The condenser pressure drop shall be measured from the inlet waterbox or its nozzle to the outlet waterbox or its nozzle at the same elevation of the condenser. The pressure-drop measurements shall be made at the same time as the condenser test. Methods for measuring the condenser pressure drop are given in subsection 4-10. The pressure drop across the condenser shall be corrected from actual to nominal design flow using the procedure described in Section 5.

Section 4

Instruments and Methods of Measurement

4-1 PURPOSE AND INTENT

This Section describes the instruments and the methods required for the performance test. Table 4-1-1 lists the instrumentation, with test-point location and required accuracy. Achievement of the required accuracy for each measurement parameter is the single most important criteria in selecting the appropriate method and location of measurement.

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

This Code shall not be construed as preventing the use of advanced technologies or methods of measurement not explicitly described herein, provided that the accuracy requirements of Table 4-1-1 are achieved.

4-2 LOCATION OF TEST POINTS

4-2.1 General

Figure 4-2.1-1 illustrates the location of the test points. Test points not required to conduct the test may be included for any other purposes.

4-2.2 Single-Pressure Surface Condenser

Figure 4-2.1-1 shows the location of the test points in the condenser that are needed to obtain the performance data required for a single-pass, single-pressure surface condenser. The final location of all test points should be determined by mutual agreement, taking into account the internal design of the condenser and external piping configuration, both of which may result in stratification at the measurement points. Test points internal to the condenser, such as basket tips and thermowells, should be located to avoid interference from the condenser's internal structural bracing and components. Field-installed test connections may require repair of the coating or lining.

4-2.3 Multipressure Surface Condenser

The test-point locations for multipass and multipressure surface condensers will be similar to those illustrated in Fig. 4-2.1-1 except for the following considerations:

(a) *Single-shell multipressure condensers* require additional condenser-pressure test points above each tube

bundle in each of the multipressure condensing zones. The performance of each zone should be closely estimated by measuring the final outlet temperature in accordance with para. 4-4.2 and proportioning the temperature rise of each zone using procedures described in Section 5.

(b) *Multiple-shell multipressure condensers* require additional pressure and temperature test points to measure the inlet and outlet cooling-water pressure and temperature for each of the multipressure condenser shells. Stratification can persist in the short length of the cooling-water crossover piping between multipressure condenser shells. Therefore, the average temperature of the inlet cooling water to the intermediate- or high-pressure shells shall be measured in accordance with procedures described in para. 4-4.2.

4-2.4 Two-Pass Surface Condensers

Test points shall be generally the same as those for the single-pressure condenser. No measurements are required at the return waterbox.

4-3 MEASUREMENT OF CONDENSER PRESSURE

4-3.1 Measurement Locations

Condenser pressure shall be measured at least 0.3 m (1 ft) and no more than 0.91 m (3 ft) above each tube bundle. A tube bundle is considered to be all tubes connected to a single waterbox. For single- and multiple-shell condensers with only one tube bundle per shell, there shall be at least three measuring points in each shell. For single-shell and multiple-shell condensers with two adjacent tube bundles per shell, there shall be at least two measuring points per tube bundle in each shell. For single-shell multipressure condensers, there shall be at least two measuring points per tube bundle in each compartment. If tube bundles are arranged one on top of the other, measurement points need only be provided for the uppermost bundle. Where three measuring points are required, they shall be located lengthwise near the quarter points of the tube bundle as shown in Fig. 4-2.1-1. Where two measuring points per bundle are required, they shall be located lengthwise near the third points of the tube bundle. In either case, the lateral position of the measuring points shall be as close to the lateral midpoint of the bundle as is practical. Care should be taken to avoid locating the measurement points in areas

Table 4-1-1 Typical Total Instrument Accuracy

Instrument Measurement, Including System Error	Test	Alternative Test (Nonmandatory Appendix A)
Condenser pressure	±0.05 in. Hg	±0.04 in. Hg
Inlet-water temperature	±0.1°F	±0.1°F
Outlet-water temperature	±0.3°F	±0.2°F
Air in-leakage	±2.0 scfm	±2.0 scfm
Cleanliness factor fouled tubes inlet temperature	N/A	0.1°F
Cleanliness factor fouled tubes outlet temperature	N/A	0.75°F
Cleanliness factor clean tubes inlet temperature	N/A	0.1°F
Cleanliness factor clean tubes outlet temperature	N/A	0.75°F
Cooling-water flow (% of reading)	±3.0%	±3.0%
Tube-bundle pressure loss (% of reading)	±2%	±2%
Dissolved oxygen	±2 ppb	±2 ppb

GENERAL NOTE: N/A = not applicable.

that may be influenced by unusually high steam velocities or by local separation zones formed by obstructions in the condenser neck.

4-3.2 Primary Pressure-Sensing Elements

For a condenser transition piece where the walls are parallel to the direction of steam flow, wall static pressure taps should be located in the transition piece, following the recommendations given in para 4-3.1 for lengthwise placement. Where wall static pressure taps cannot be used, basket tips or guide plates should be located in the interior of the condenser transition piece according to the general directions given in para. 4-3.1.

4-3.2.1 Static Pressure Taps. Static pressure taps shall conform to the requirements of subsection 4-1 of ASME PTC 19.2 [1]. In particular, care shall be taken to ensure that no obstructions exist in the vicinity of the taps, and that the taps themselves are smooth and free of burrs.

4-3.2.2 Basket Tips. Basket tips shall be constructed as shown in Fig. 4-3.2.2-1 and shall be installed at an angle between 30 deg and 60 deg to the mean flow direction. Alternatively, the construction shown for turbine exhaust pressure in ASME PTC 6 [1] should be used.

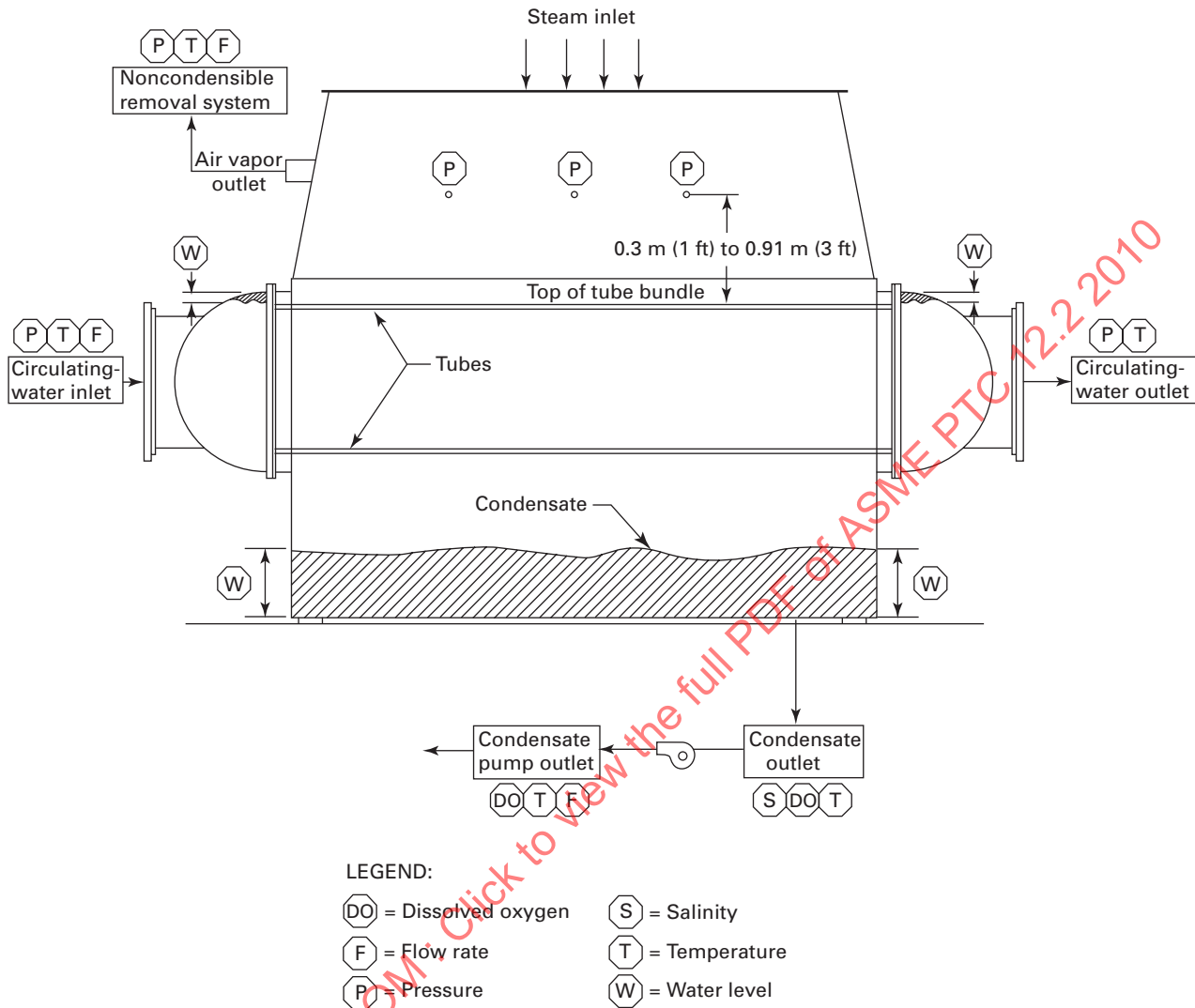
4-3.2.3 Guide Plates. Guide plates shall be constructed as shown in Fig. 4-3.2.3-1 and should be oriented so that the steam flow is parallel to the guide plates as shown in the figure.

The typical pressure-sensing element for condensers operating with medium and large steam turbine installations would be basket tips since some or all of the associated walls of the condenser transition piece would not be parallel to the direction of steam flow. Pressure-sensing piping for the pressure measurement shall conform to the general requirements of ASME PTC 19.2 [1]; the minimum diameter shall be $\frac{3}{8}$ in. In particular, care should be taken to ensure that all piping and connections are air and steam tight, are connected by the most practical route, and pitch continuously downward from the pressure-measurement device to the pressure-sensing element to ensure drainage. The gauges shall be mounted so as to be free from excessive vibration. Each pressure-measurement point should be provided with a dedicated pressure-measuring device, or manifolds should be used to switch a single pressure-measuring device to several pressure-measuring points. Care shall be taken to ensure that the manifold provides vacuum-tight isolation of each measurement point and that the line and manifold are purged of any water. Manifolds shall not be used as a means to average pressure readings by connecting several measuring points to the same pressure-measuring device simultaneously.

4-3.3 Pressure Transducers

Mercury manometers shall not be used because of the environmental and operation hazards they present in case of an accidental spill of the mercury. Electronic absolute-pressure transducers are recommended provided that they are calibrated before the test program using NIST-traceable standards. For more information, refer to ASME PTC 19.2 [1].

Fig. 4-2.1-1 Location of Condenser Test Points



4-4 COOLING-WATER TEMPERATURE

4-4.1 Inlet Temperature

4-4.1.1 Location of Measurement Points. Because the cooling water at the condenser inlet is generally well mixed, only one temperature-measuring device is usually necessary in each cooling-water inlet conduit. At installations where there are concerns about adequate inlet cooling-water mixing, the multiple-point measurement procedure described in Nonmandatory Appendix A should be followed. Measurements should be taken by inserting a temperature-measuring device directly into the flow or from a thermowell that extends at least 150 mm (6 in.) into the flow but no farther than the mid-point if the pipe diameter is less than 300 mm (12 in.). If a well is used, it should be clean and filled with a suit-

able heat-transfer medium, such as glycol thermal paste, and insulation should be used around the probe to minimize heat exchange with the environment.

If a single-point measurement is used, the measurement should be made either at the inlet pipe or in the inlet waterbox.

4-4.1.2 Instruments. Inlet temperature measurements shall be made with instruments having an accuracy of $\pm 0.06^{\circ}\text{C}$ ($\pm 0.1^{\circ}\text{F}$). Several instruments capable of achieving this accuracy are suitable for use in condenser testing, such as resistance-temperature devices (RTDs), thermocouples (TCs), thermistors, and liquid-in-glass thermometers. Mercury thermometers shall not be used because of the potential environmental hazards posed by the mercury in case of breakage. For more informa-

Fig. 4-3.2.2-1 Basket Tip

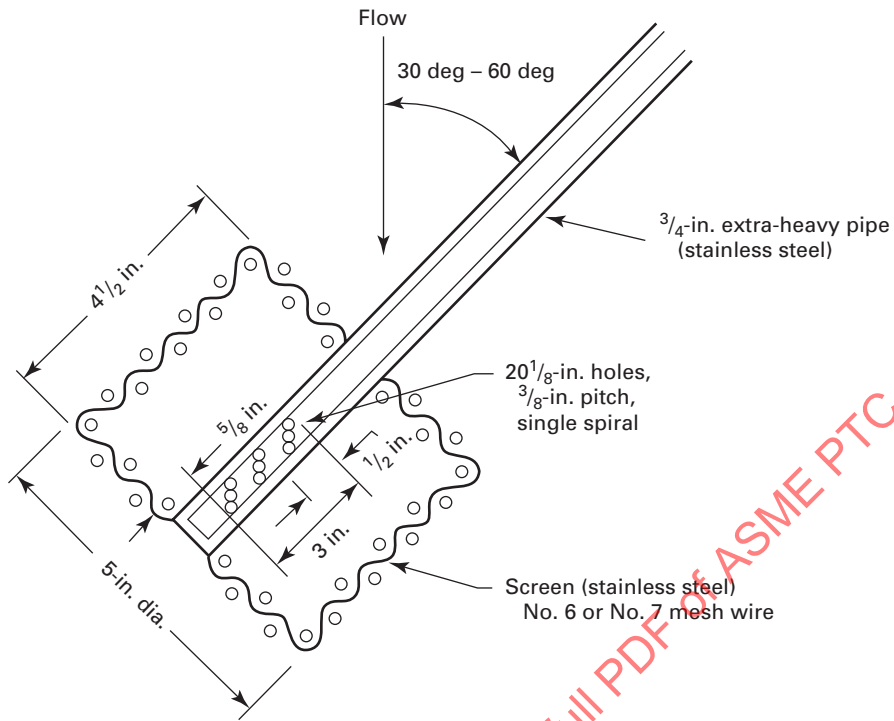
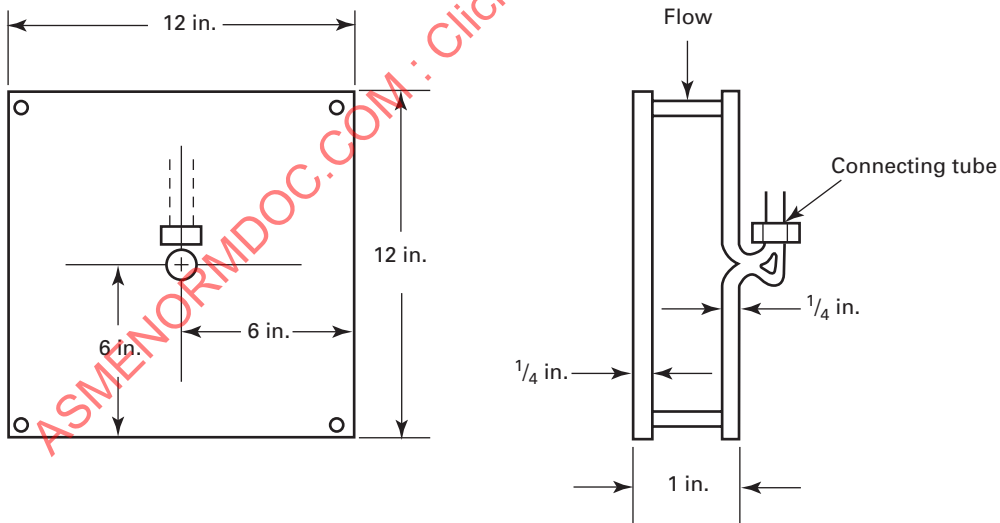


Fig. 4-3.2.3-1 Guide Plate



tion, refer to ASME PTC 19.3 [1]. Liquid-in-glass thermometers should be of the total-immersion type with etched stems. Thermometers should have clearly readable graduations of 0.06°C (0.1°F). If the thermometer was calibrated for total immersion, an emergent stem correction factor as described in ASME PTC 19.3 [1] should be applied. The thermometer should be isolated from heat sources and be well illuminated. The thermometer should be inspected before and after the tests to ensure that it is in good physical condition, with no breaks, cracks, or liquid separation.

Type E thermocouples are recommended for the temperature range usually encountered at normal cooling-water temperatures, because they are more sensitive. Continuous leads from the measuring tip to the thermocouple readout shall be provided to avoid errors due to thermally induced EMF at splice junctions.

One hundred-ohm platinum RTDs and thermistors with a nominal impedance of greater than $1,000\ \Omega$ at 0°C (32°F) are recommended. For RTDs and thermistors, either a three- or four-wire measurement is acceptable. The four-wire method is recommended, although the three-wire method may be used provided that the required measurement uncertainty can be achieved. If the three-wire method is used, all RTD leads shall be continuous back to the measuring device to avoid errors due to unequal splice resistance. This is not a requirement with the four-wire method or with thermistors.

4-4.1.3 Calibration. Temperature-measuring devices shall be calibrated in accordance with the manufacturer's procedure using NIST-traceable standards [1]. If either thermocouples or three-wire RTDs are used, calibration shall include the lead wires. A minimum of five calibration points covering the expected range of temperatures shall be taken.

4-4.2 Outlet Temperature

4-4.2.1 Location of Measurement Points. The measurement of outlet temperature is more difficult than that of inlet temperature because uneven heat transfer or outlet-temperature stratification often occurs in condensers, and there may be nonuniform temperatures in the outlet pipe.

Measurement of the discharge temperature should be made far downstream from the condenser, where the discharge is well mixed and the temperature is uniform. This location is acceptable if the cooling-water discharge from the unit under test does not mix with any other flow, and if it can be determined that no stratification exists.

If another flow is mixed with the outlet cooling-water flow upstream of the temperature measurement point, the thermal effect of that flow shall be accounted for.

It has been determined that heat loss to the environment is not significant at less than 1,000 diameters downstream from the condenser.

If an acceptable, well-mixed location cannot be found, then the outlet temperature shall be determined from an array of temperature measurements at each outlet pipe, at a suitably convenient location, as described in Nonmandatory Appendix A.

4-4.2.2 Instruments. Inlet temperature measurements shall be made with instruments having an accuracy of $\pm 0.06^{\circ}\text{C}$ ($\pm 0.1^{\circ}\text{F}$). Several instruments capable of achieving this accuracy are suitable for use in condenser testing, such as resistance-temperature devices (RTDs), thermocouples (TCs), thermistors, and liquid-in-glass thermometers. Mercury thermometers shall not be used because of the potential environmental hazards posed by the mercury in case of breakage. For more information, refer to ASME PTC 19.3 [1]. Liquid-in-glass thermometers should be of the total-immersion type with etched stems. Thermometers should have clearly readable graduations of 0.06°C (0.1°F). If the thermometer was calibrated for total immersion, an emergent stem correction factor as described in ASME PTC 19.3 [1] should be applied. The thermometer should be isolated from heat sources and be well illuminated. The thermometer should be inspected before and after the tests to ensure that it is in good physical condition, with no breaks, cracks, or liquid separation.

Type E thermocouples are recommended for the temperature range usually encountered at normal cooling-water temperatures, because they are more sensitive. Continuous leads from the measuring tip to the thermocouple readout shall be provided to avoid errors due to thermally induced EMF at splice junctions.

One hundred-ohm platinum RTDs and thermistors with a nominal impedance of greater than $1,000\ \Omega$ at 0°C (32°F) are recommended. For RTDs and thermistors, either a three- or four-wire measurement is acceptable. The four-wire method is recommended, although the three-wire method may be used provided that the required measurement uncertainty can be achieved. If the three-wire method is used, all RTD leads shall be continuous back to the measuring device to avoid errors due to unequal splice resistance. This is not a requirement with the four-wire method or with thermistors.

4-4.2.3 Calibration. Temperature-measuring devices shall be calibrated in accordance with the manufacturer's procedure using NIST-traceable standards [1]. If either thermocouples or three-wire RTDs are used, calibration shall include the lead wires. A minimum of five calibration points covering the expected range of temperatures shall be taken.

4-5 COOLING-WATER FLOW

The cooling-water flow is required to assess the performance of the condenser. The cooling-water flow rate

shall be defined as the flow rate of the water inside the condenser tubes. The source of cooling water can be a river, lake, ocean (once-through cooling), or a cooling tower (closed loop). If the source of cooling water is a cooling tower, measurements of the cooling-water flow rate shall be made in the piping leading to the tower or in its individual operating cells. If flow measurement in the hot-water piping to the tower is not possible, due either to an inaccessible location or one that is likely to contain distorted velocity profiles, measurements should be made in the equipment-return piping from the tower. If the measurement is impacted by flow streams not accounted for at the flow-measurement point, additional flow measurements may be required to accurately calculate the cooling-water flow rate.

Cooling-water flow determination is required for computing the tube-water velocity and for determining condenser heat load (condenser duty). To ensure the highest level of measurement accuracy, consideration should be given to flow measurement at the design stage of any specific project, and a suitably accurate method of measurement and a corresponding instrument location should be agreed upon by the purchaser and manufacturer from the start.

Flow devices should be installed at points in the cooling-water system where a fully developed velocity profile exists; for example, distortions of the velocity traverse, helical swirls, or vortices should be minimized. Choosing a desirable measurement location has a significant impact on the accuracy of any flow measurement, regardless of the instrumentation used. Due to the nature, variation, and the number of accurate measurements required, the energy balance method should not be used to determine the flow rate except when performed concurrently with an ASME PTC 6 test [1]. The use of pump curves or other methods not discussed herein could result in an inaccurate determination of water flow rate. The dye-dilution method has been successfully applied in some installations, particularly in once-through cooling-water systems, but it has been unsuccessful in some recirculating systems. A differential producer such as an orifice plate, flow nozzle, or venturi meter should be used for units with cooling-water flows no greater than 15,000 gpm.

The following three methods of cooling-water flow measurement are recommended for measuring flow in large conduits; the chosen method must be capable of providing an uncertainty of no greater than $\pm 3\%$:

- (a) velocity traverse
- (b) tracer-dye dilution
- (c) ultrasonic time-of-travel

Considerations concerning the application of the three methods listed above to steam condensers are covered in this Section. The cooling-water flow-rate test should be conducted concurrently with the heat-transfer test.

4-5.1 Velocity Traverse Methods

Velocity traverse methods are generally most applicable to the measurement of flow in large conduits in which the size of the probe will not affect the measured flow. ASME PTC 19.5 [1] describes the general considerations for acceptable velocity traverse methods. The Fehcheimer and Keil pitot-static-type probes as well as the time-of-transit ultrasonic meter are explicitly recommended, although other instruments that meet uncertainty requirements may be used.

If the Fehcheimer probe is used, the directional-sensing capabilities of the probe should be used to determine the local flow angle, and this flow angle should be incorporated into the flow determination. Due to the probe geometry, it can be used only for a 10-point traverse [see Fig. 4-5.1-1, illustration (a)], regardless of pipe size.

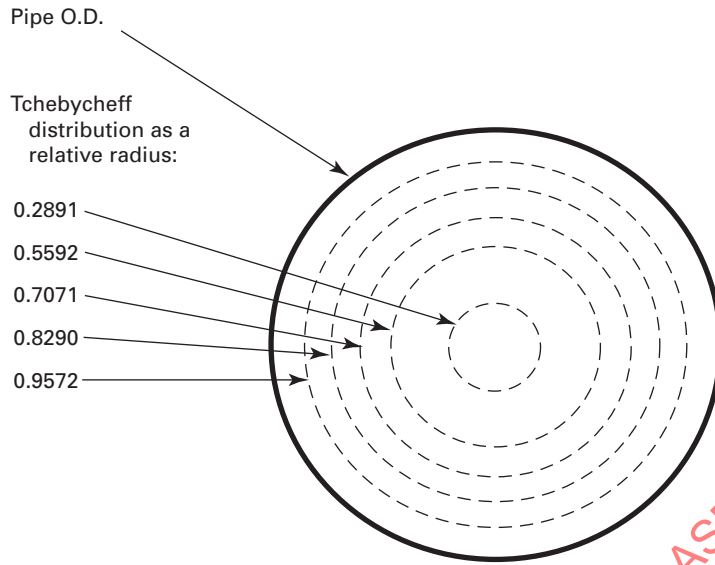
Before testing, pitot-static probes shall be inspected and calibrated by a hydraulic laboratory to an accuracy of $\pm 1\%$ using standards traceable to the NIST or other nationally recognized standards bodies. Calibrations shall cover the range of Reynolds numbers (based on probe diameter) expected in the velocity measurements. A post-test calibration shall be conducted if inspection reveals there was damage to the probe. A deviation of more than 1% between the pretest and post-test calibrations shall be cause for investigation. It may require a retest.

Differential-pressure measuring devices shall be calibrated before the test to an accuracy of at least $\pm 0.25\%$ of the maximum differential pressure expected. Mechanical gauges, manometers, and electronic differential pressure transducers are acceptable, provided that the stated accuracy requirements are met.

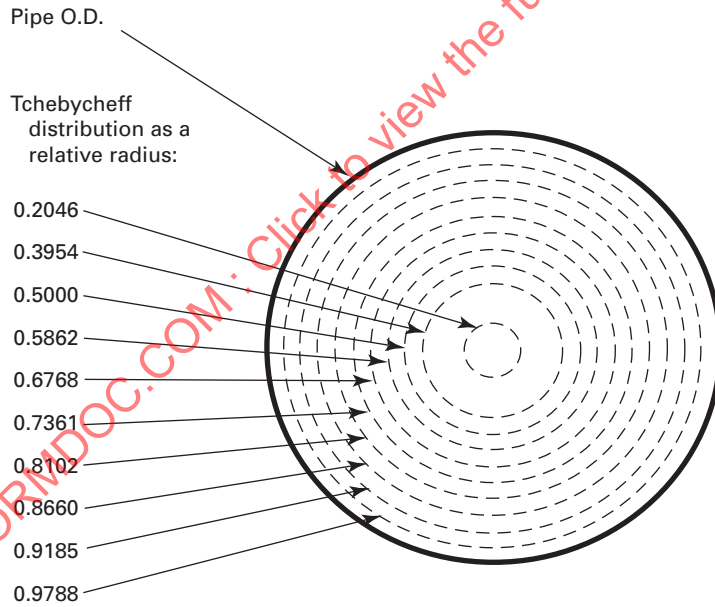
The velocity probe should be inspected for damage periodically during testing. If any damage to the probe is noted, all measurements made since the previous inspection shall be retaken with another calibrated probe. A velocity probe may experience vibration under certain flow conditions, especially with larger-diameter or poorly supported test points. If such vibration is detected, the cause of the vibration shall be corrected, if possible. Measurements taken under conditions of significant probe vibration shall not be considered valid. Indicators of probe vibration include a sharp change (usually a rise) in the probe differential when the probe position is changed slightly, physical vibration of the exposed part of the probe, or a relatively sudden onset of a high level of periodic pressure pulsations.

At least 10 diameters of straight, unobstructed piping shall exist upstream and 5 diameters downstream of the measuring station. Traverses shall be taken along at least 2 diameters opposed at 90 deg. The traverse locations shall follow the Tchebycheff weighing scheme described in ASME PTC 19.5 [1] with a minimum of 10 points along each diameter. An example of acceptable traverse points is shown in Fig. 4-5.1-1. The volume flow

Fig. 4-5.1-1 Recommended Velocity Traverse Probe Positions



(a) 10-Point Traverse (I.D. \leq 24 in.)



(b) 20-Point Traverse (I.D. \leq 24 in.)

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rate is determined by integrating velocities measured at a number of points in a plane perpendicular to the water direction. For this reason, accurate measurements of the internal pipe diameter, pipe shape (out-of-roundness), and location of the probe tip are extremely important. In addition, response times for specific tube designs can vary significantly; therefore, attention should be given to ensure that equilibrium has been reached at each measurement point. The traverse locations shall be based on an equal-area weighting method or the Tchebycheff weighting scheme described in ASME PTC 19.5 [1]. A 10-point diametrical traverse shall be used for pipes of 24 in. internal diameter or less; a 20-point diametrical traverse shall be employed for larger diameter pipes. An example of acceptable traverse points for each is shown in Fig. 4-5.1-1.

4-5.1.1 Internal Pipe Diameter. Internal pipe diameters are critical to the application of the traverse method. Errors in determination of the internal pipe diameters affect both the positions of the traverse locations and the area used to determine total water flow. Errors in area directly affect the calculated result of the condenser performance.

4-5.1.1.1 Measurement of Internal Pipe Diameter. Measurement of the internal pipe diameter can be made using a device that can be deployed through the valve, as with the pitot tube. Such a device would be deployed from far side to near side as nearly normal to the pipe centerline as possible, and the difference in insertion measured on the external portion of the device. Alternatively, the pitot tube itself can be used to approximate this measurement by insertion to the far side of the pipe and, while reading deflection on the manometer, retraction until the deflection exactly reaches zero. The difference in insertion is the pipe internal diameter. It is important to note that if the pipe fitting for the tap location is welded or otherwise attached such that it is not flush with the inside of the piping, an error in internal pipe diameter can result as the zero deflection point will not be at the pipe wall. If the taps are skewed with respect to the true pipe diameter, a dimension either greater or smaller than the diameter is possible. Internal diameter measurements shall be used for calculation of the traverse points, in any event.

4-5.1.1.2 Determination of Internal Pipe Diameter by Calculation. If for some reason the internal pipe diameter can't be measured directly as described in para. 4-5.1.1.1, nominal values should be used or the internal diameter should be determined by calculation. If the wall thickness of the piping is known from pipe drawings, the circumference should be measured and the internal diameter calculated by subtracting double the wall thickness from the external diameter determined

from the measured circumference. The uncertainty of this method is very high. In new and clean installations, the calculation method should yield acceptable results, but adhering to the prescribed uncertainty requires verification of piping's internal cleanliness and physical dimensions at the measurement point.

4-5.2 Tracer-Dye Dilution Methods

Tracer-dye dilution methods are particularly applicable to the measurement of flow in large conduits where no other suitable measurement methods are available. Although no formal standard on their use currently exists, the method is discussed in ASME PTC 19.5 [1]. If this technique is used, the parties to the test shall agree upon the details of implementation, provided that the guidelines outlined here are followed. It should be noted that because of the constantly rising background concentration typical in closed-circuit cooling towers, there is no industry consensus that the tracer-dye dilution method can be accurately applied in such environments. The method is best suited for once-through cooling circuits where background concentrations remain constant. Key requirements are as follows:

(a) Complete mixing of the tracer must be achieved for an accurate flow measurement. As a general guideline, 100 diameters of pipe should extend between the injection and sampling points. However, turbulence producers (e.g., pumps, bends) can reduce the number of pipe diameters required for complete mixing. The presence of complete mixing at the sampling cross section shall be determined before testing by sampling a traverse of nine equally spaced points along 1 diameter at the sampling cross section and verification that the concentrations at all points agree to within $\pm 1\%$. This sampling shall be conducted within $\pm 10\%$ of the flow at which the condenser tests are to be run. Injection of dye should be through a manifold or at a single point in the flow, so long as complete mixing of the dye at the sampling point is verified as described above.

(b) The background concentration of the measured water shall not be altered by the recirculation of the injected dye. Precautions shall be taken if the possibility exists that the injected dye may recirculate to the injection point. In the case of a time-varying flow, such as a tidally influenced estuary, those conducting the test shall demonstrate, by measurement before the start of the test, that no dye recirculation exists. In the case of a closed-cycle cooling system, those conducting the test shall demonstrate, by measurement before the start of the test, that any previously injected dye is thoroughly mixed throughout the cooling-water system and that the background concentration is accurately calculated. As a rule, about five cycle-recirculation times are required for complete mixing to be achieved (the cycle-recirculation time is the total volume of water in the cooling-water system divided by the cooling-water flow rate).

(c) When the background concentration begins to rise above the previously calculated value, the testing should be stopped.

(d) If the test must proceed with a rising background concentration, a method to properly correct for the condition shall be determined and agreed upon.

(e) Both tracer injection and sampling should occur on either the inlet-water or the outlet-water side of the condenser. If injection and sampling occur on the same side of the condenser, either continuous sampling or grab samples should be used. If injection and sampling occur on the opposite sides of the condenser, temperature effects shall be taken into account. For Rhodamine WT dye, the temperature correction of various samples should be made to a common temperature, using the following equation [2]:

$$F_s = F_\theta^{-0.027(T_s - T_w)} \quad (4-5-1)$$

where

F_s = the fluorescence at standard temperature, T_s , °C

F_θ = the measured fluorescence at temperature corrected for background and instrument offset, T_w , °C

(f) The dye shall exhibit minimal tendency to absorb into organic or inorganic surfaces. Recent applications of this technique have most often used Rhodamine WT fluorescing dye as the tracer; however, any dye that can be shown to be conservative (not subject to adsorption or other loss mechanisms) shall be acceptable.

(g) The flow should be free of any chemicals (e.g., chlorine) or silt concentrations that can affect the ability to accurately measure the concentration of dye.

(h) If the mass or volume of the injected dye is not directly measured during the test, the injection apparatus shall be calibrated for injection flow with water from the system to be tested.

(i) The dye concentration shall be measured using a calibrated precision fluorometer. The fluorometer or other concentration-measuring device shall be calibrated before and after the test using a minimum of three calibration solutions made with the system water and having dye-concentration levels above and below the level expected of the test. Instrument accuracy shall be no more than $\pm 1\%$.

The uncertainty of the injection rate shall be $\pm 0.5\%$ or better.

Periodic field calibration of the tracer injection apparatus and the fluorometer during testing should be conducted to ensure data integrity. The dye concentration shall reach steady state at the sampling point before data to be used in the flow determination are taken. This determination shall be made by continuously monitoring the tracer concentration at the sampling cross section.

General considerations relating to the application of Rhodamine WT or similar tracers may be found in *Flow Measurements in Sanitary Sewers by Dye Dilution* [3].

(j) Chemical treatment that is introduced into the flow before the sampling point should be shut off before the test. In the case of a closed-cycle system, a prolonged period of no treatment should be required to purge the cooling system of treatment chemicals. Chlorine, in particular, may affect Rhodamine dye.

(k) Care shall be taken to ensure that no flow is introduced or removed between the injection and sampling stations. It is not sufficient to simply account for these flows, since a small inflow or outflow can lead to a large measurement error. An exception is that any outflows between the section at which complete mixing has been verified and the sampling station will not affect the measured flow.

4-5.3 Ultrasonic Time-of-Travel Methods

In all conduits, particularly large ones, flow may be measured using the multiple-path, ultrasonic time-of-travel-type flow-measurement method. The provisions given in ASME PTC 18 [1] under the heading "Acoustic Method" shall govern the application of this method. An ultrasonic clamp-on transducer may be used provided that it complies with all requirements to follow. It is emphasized that the time-of-travel method is very different than the Doppler technique. The Doppler-type instruments will not provide sufficient accuracy to satisfy the requirements of this Code.

The ultrasonic time-of-travel measurement shall be made immediately preceding the test, during the test, or immediately following the test. The internal pipe diameter is critical to the application of the ultrasonic method. Errors in determination of the internal pipe diameters affect the area used to determine total flow, and that directly alters the calculated result for condenser performance. The provisions given in ASME PTC 19.5 [1] shall be used as a guide in the application of this method. Because of the constantly improving technology in the ultrasonic field, the final application shall be based on a combination of the requirements listed in the equipment manufacturer's recommendations, in ASME PTC 19.5, and in the guidelines in ASME PTC 18 [1].

Experience in cooling-tower testing has shown that the ultrasonic instrument and its specific application to a particular test may have a measurement inaccuracy exceeding that required by this Code; therefore, careful consideration shall be taken when using the acoustic method to ensure the repeatability and accuracy of the measurement. All instruments and sensors used shall be NIST traceable. The meter and transducers shall have been calibrated in similar conditions to that of the test in question. The similarity shall include geometry modeled and Reynolds-number range.

In addition, if the method is proposed, the calibration data and previous comparative experience of the particular meter shall be required to be provided, prior to its acceptance and installation for a test, as evidence of its measurement accuracy for the specific test conditions. That calibration information and data shall become part of the test report.

A minimum of four parallel chordal paths shall be measured regardless of the size of the conduit. As a minimum, at least 10 diameters of straight pipe upstream and 5 diameters downstream shall be provided without any obstructions (e.g., an open butterfly valve) at either end.

The time-of-travel instrumentation shall be calibrated at the zero-flow condition before and after the test to ensure proper and accurate operation. Zero-flow calibration shall be conducted in a full-pipe condition only. To further verify accuracy during the calibration, the acoustic velocity should be measured with the acoustic device and compared with the published values for the speed of sound in the process fluid. Any discrepancies shall be investigated.

Because this method may be adversely affected by the presence of silt and other particulate or air bubbles in the flow, it should also be verified that the source water is suitably clean before the metering system is installed.

Since permanent ultrasonic time-of-travel systems may be relatively difficult and expensive to install on large-diameter conduits, provision for their installation should be made during design and construction of the cooling system. At the time of installation, the true diameter of the conduit cross-sectional area shall be determined.

4-6 NONCONDENSIBLE FLOW

Noncondensibile flow shall be measured by devices located at or near the discharge of the evacuating apparatus by one of the following methods once during the test and checked by one of the remaining methods:

- (a) orifice
- (b) rotameter
- (c) mechanical anemometer
- (d) volumetric technique
- (e) flow sensor
- (f) other methods or instruments that can be shown to be accurate

4-6.1 Preliminary Check

To ensure the removal equipment itself does not leak, the suction valve to the noncondensibile-gas removal equipment shall be temporarily closed within 2 hr prior to the test. A quick measurement of the noncondensibile gas shall then be made and the suction

valve reopened. Any noncondensibile quantity that results from that measurement should be subtracted from subsequent noncondensibile measurements of the test. Since the condenser steam spaces have large volumes, no rapid rise in condenser test pressure or other adverse operating condition should be expected during the short duration of this preliminary noncondensibile gas measurement.

Table 3-4-1 shall provide one criterion of the maximum noncondensibile allowed by the Code. The condenser air in-leakage should be reduced to be compatible with Table 3-4-1 by finding the sources of some of the leakage and making repairs within a week prior to the test.

4-6.2 Specific Guidance on Use of Noncondensibile Devices

4-6.2.1 Orifice. The orifice plate shall meet the specifications described in ASME PTC 19.5 [1]. Provided that all specified installation criteria are followed, no calibration of the orifice meter is required. Particular attention should be paid to ensuring that adequate lengths of straight pipe upstream and downstream of the orifice are available, that the pressure taps are properly located and finished, and that the tubing to the differential pressure gauge is of the proper diameter and is sloped continuously downward from the gauge to the orifice, to avoid accumulation of water. Gauge pressure and temperature of the discharge shall be measured either upstream or downstream of the orifice plate.

The flow shall be determined according to the equations for gas flow through an orifice as given in ASME PTC 19.5 [1]. Gas properties, such as the expansion factor, density, and viscosity, shall be determined assuming that the orifice flow consists of saturated air. For convenience, simplified equations yielding sufficient accuracy for purposes of this paragraph are given in Nonmandatory Appendix H.

4-6.2.2 Rotameter. The piping and valving of the circuit shall be lined up and the lines purged of water. The instrument supplier's general recommendations for measurement shall be followed.

4-6.2.3 Mechanical Anemometer. The instrument supplier's general recommendations for measurement shall be followed. The discharge vapor component in the gas mixture shall be accounted for.

4-6.2.4 Volumetric Technique. Effective use of the volumetric technique requires two people. A light bag shall be used for measurement, and the test stopped as soon as the bag or device is full. The discharge vapor component in the gas mixture shall be accounted for.

Gloves should be used to safely handle the temperatures encountered.

4-6.2.5 Flow Sensor. The instrument supplier's general recommendations for measurement shall be followed. The discharge vapor component in the gas mixture shall be accounted for.

4-7 HOTWELL LEVEL

The level of water in the hotwell shall be monitored during the test and remain within design limits for the duration of the test.

4-8 WATERBOX LEVEL

The level of water in the waterbox shall be monitored during the test and remain full for the duration of the test.

4-9 TUBE CLEANLINESS

4-9.1 Introduction

The goal of the following procedure is to provide assurance that the tubes are physically clean during the subsequent performance test. The effect is that condenser performance calculations at the test conditions shall be computed with a zero fouling resistance. The resulting test evaluation parameters shall then be adjusted to the design values using the apparent condenser percent cleanliness that was specified by the manufacturer, and the tube shellside and waterside resistances shown in Section 5.

When a 100% clean designation of tube cleanliness is in doubt by one party before testing, a tube cleanliness evaluation shall be performed. The cleanliness test is necessary to determine the extent of fouling. The cleanliness test consists of two parts: video inspection and deposit sampling. The test sequence flowchart is presented in Fig. 4-9.1-1.

First, just prior to acceptance testing, 100% of the internal tube walls of the condenser tubes shall be cleaned with the best available technology that is suitable for removal of deposits characteristic of the cooling-water supply, temperature, and tube material, and that is mutually acceptable to the parties to the test.

In the event that a continuous ball cleaning system is being utilized, it shall represent the method to satisfy the requirement for cleaning 100% of the tubes. The ball cleaning system, however, must have been effectively operated and maintained using the balls at the specified frequency, number, and ball-surface condition and must remain in this operation from the time of the introduction of the cooling water to the condenser to the time of the condenser-performance test.

4-9.2 Video Inspection of Condenser-Tube Internal Diameters

As indicated, when the tube cleanliness is in doubt by one party to the test, trained technicians utilizing a video scope and computerized recording device shall inspect the condenser tubes. The tubes to be examined shall be selected by the condenser manufacturer, his designee, or as mutually agreed upon by the parties. The inspection with a boroscopic video shall be of the entire length of at least three to five tubes from four to six sectional areas for the particular tube-bundle pattern and air-removal zone of each pass, as applicable. This video examination shall be recorded and viewed.

4-9.3 Deposit Sampling

If the presence of fouling is observed during the tube video inspection, then deposit sampling is required. The deposits shall be sampled by the use of a mechanical cleaner, scraper, or brush, as determined by the parties to be suitable for the removal of deposits characteristic to those known to occur under similar cooling-water system characteristics. The deposit samples shall be taken from the same three to five tubes in four to six sectional areas of the particular tube-bundle pattern and the air-removal section of each condenser tube pass, as applicable.

Typically, utilizing 300-psi water pressure at 36-gpm flow, the proper size and type of tube cleaner is propelled through the condenser tube. All water, deposits, residue, and the tube cleaner shall be collected in a specimen container for analysis and determination of the most effective cleaning method. The presence of deposits warrants cleaning 100% of the condenser tubes.

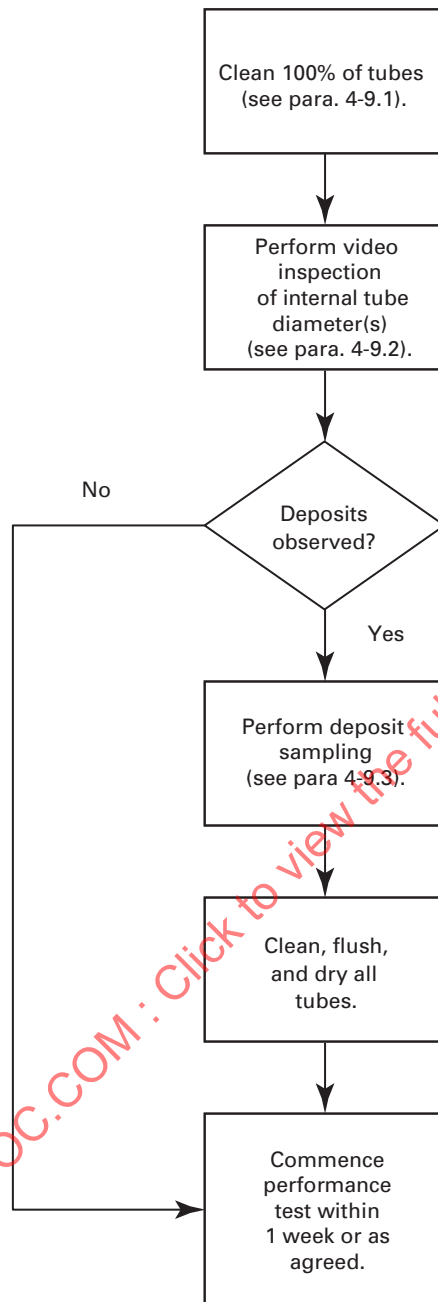
4-9.4 Conducting the Subsequent Performance Test

After all of the condenser tubes are cleaned in accordance with para. 4-9.3 and a satisfactory agreement is reached among the parties that the tubes are clean, the tubes shall be flushed with potable water or similar clean water and adequately dried until the introduction of the cooling water. The performance test shall commence within 1 week, or as mutually agreed upon, of introducing cooling water into the condenser tubes.

4-10 WATERBOX DIFFERENTIAL PRESSURES

Differential pressure gauges shall be provided to measure the pressure drop between the inlet and outlet waterbox nozzles. There shall be at least one differential gauge for each parallel water circuit in the condenser. The gauges shall be calibrated before the test to $\pm 1\%$ of the maximum expected differential. Mechanical gauges or electronic differential pressure gauges are acceptable.

Fig. 4-9.1-1 Tube Cleanliness Test-Sequence Flowchart



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4-11 DISSOLVED OXYGEN

4-11.1 General

This method describes the measurement of the dissolved-oxygen concentration of the condensate. Prior to conducting the measurements described in this subsection, the conditions for testing in accordance with para. 3-16.1 of this Code shall be achieved.

4-11.2 Sample Extraction

Accurate measurements of dissolved oxygen from a subatmospheric vessel are difficult. Sampling of the condensate for dissolved oxygen shall be performed by extracting condensate from the condensate outlet piping as close as possible to the hotwell but prior to addition of any oxygen-scavenging chemicals (see Fig. 4-2.1-1). Extraction shall be made using a sampling pump. Care shall be taken to avoid any air ingress in the sample line from the hotwell outlet piping to the sampling pump. Samples shall be measured in each hotwell outlet that is in use.

The sample nozzle shall extend into the condensate piping 10 cm (4 in.) or 25% of the pipe diameter, whichever is less. Stainless steel tubing shall be used to connect the sample nozzle to the dissolved-oxygen probe, and to connect the probe to the sampling pump. The sampling pump discharge should be routed back to the condenser under vacuum to reduce sampling-pump head pressure.

It may be easier to take the sample downstream of the condensate pump. If this sample meets the requirements of the test, the results of the downstream sample shall be acceptable for the test.

4-11.3 Sample Conditioning

Samples for continuous-flow oxygen analyzers should be at flow rates and temperatures recommended by the instrument manufacturers. Flow and temperature shall be held constant during the tests.

If sample tubing is used to transport the sample to a remote location, the tubing shall be sized to maintain a minimum velocity of 1.5 m/s to 2 m/s (5 ft/sec to 6 ft/sec).

Prior to the tests, sample lines and instrumentation shall be flushed for a sufficient time to ensure that lines are free from air bubbles or pockets.

4-11.4 Oxygen Analysis

Portable or in-line oxygen analyzers using membrane-covered galvanic or polarographic oxygen sensors should be used as the method of analysis. The instrument used shall have a lower detection limit of 1 µgr/l (1.0 ppb).

The instrument shall be calibrated before and after the test. If calibration is performed using atmospheric oxygen, the analyzer shall be given sufficient time to reach equilibrium with the condensate dissolved-oxygen concentration.

It is recommended that the instrument analysis be verified by a wet chemistry technique per ASME PTC 12.3 [1].

If the oxygen sensor fouls from condensate contaminants, the titrimetric method shall become the recommended method of analysis. The sample shall be extracted in the same manner as described in para. 4-11.2.

4-12 CONDENSATE TEMPERATURE

Condensate temperature measurements shall be made in accordance with the general procedures described in para. 4-4.1. The thermowells should be located as close as practical to the condenser and in an operating condensate pump suction line.

4-13 SALINE OR BRACKISH WATER CONCENTRATION

Salinity measurements shall be made by using Method 2520 for "Salinity" from *Standard Methods for the Examination of Water and Wastewater* [4].

Section 5 Computation of Results

5-1 BASIC HEAT-TRANSFER RELATIONS

This Section defines all the computations required to obtain results from the various types of condenser tests addressed in the Code. For both single-pass and two-pass condensers, these include the heat-transfer coefficients, adjustments to design conditions, fouling resistance, subcooling, condensate dissolved oxygen, tubeside pressure drop, noncondensable gas flow, and measurement uncertainty. Though the basic equations are the same, multipressure condenser performance assessments differ slightly, as is described in para. 5-2.8. Note that when the complete equations are given, SI units are assumed. Using U.S. Customary units may change the equation. In these cases, the equations for U.S. Customary units immediately follow those for SI units.

Note that there is no requirement to conduct an uncertainty analysis, either pretest or post-test.

5-1.1 Condenser Heat Load

The condenser heat load shall be computed according to the following equation:

$$Q^+ = \frac{w^+ \times c_p^+ \times (T_2^+ - T_1^+)}{C} \quad (5-1-1)$$

where

$C = 3.6$ for SI units

$C = 1$ for U.S. Customary units

5-1.2 Overall Heat-Transfer Coefficient

The overall heat-transfer coefficient at the test conditions shall be computed as follows:

$$U^+ = \frac{Q^+}{A_o \times LMTD^+} \quad (5-1-2)$$

where

$$LMTD^+ = \frac{(T_2^+ - T_1^+)}{\ln \left[\frac{(T_s^+ - T_1^+)}{(T_s^+ - T_2^+)} \right]} \quad (5-1-3)$$

The saturated steam temperature, T_s^+ , corresponding to pressure P_s^+ shall be determined from the ASME Steam Tables [5].

5-1.3 Tube-Wall Resistance

The tubeside resistance shall be computed as follows:
(SI Units)

$$R_m^+ = \frac{D_o}{2 \times k_m} \times \ln \left(\frac{D_o}{D_i} \right) \quad (5-1-4)$$

(U.S. Customary Units)

$$R_m^+ = \frac{d_o}{24 \times k_m} \times \ln \left(\frac{d_o}{d_i} \right) \quad (5-1-5)$$

5-1.4 Tubeside Resistance

The tubeside thermal resistance calculation shall be taken from Rabas and Cane [6]:

$$R_i^+ = \left[0.0158 \times \frac{k^+}{D_i} \times (Re^+)^{0.835} \times (Pr^+)^{0.462} \right]^{-1} \quad (5-1-6)$$

where

$$Pr^+ = \frac{1000 \times c_p^+ \times \mu^+}{k^+} \quad (5-1-7)$$

$$Re^+ = \frac{\rho^+ \times v^+ \times D_i}{\mu^+} \quad (5-1-8)$$

$$v^+ = \frac{w^+}{3600 \times \rho^+ \times \frac{N}{n} \times \frac{\pi}{4} \times D_i^2} \quad (5-1-9)$$

This equation is simplified for calculation in U.S. Customary units:

$$R_i^+ = 0.0451 \times \left(\frac{\mu^{+0.373}}{k^{+0.538} \times \rho^{+0.835} \times c_p^{+0.462}} \right) \times \frac{d_i^{0.165}}{v^{+0.835}} \quad (5-1-10)$$

where

$$v^+ = \frac{w^+}{25 \times \rho^+ \times \frac{N}{n} \times \frac{\pi}{4} \times d_i^2} \quad (5-1-11)$$

Cooling-water fluid properties shall be evaluated at the average bulk water temperature, T_B , which is defined as

$$T_B^+ = 0.5 \times (T_2^+ + T_1^+) \quad (5-1-12)$$

5-1.5 Shellside Resistance

The shellside resistance at the test conditions shall be determined by difference as follows:

(SI Units)

$$R_s^+ = \frac{1}{U^+} - R_m^+ - R_i^+ \times \left(\frac{D_o}{D_i} \right) - R_f^+ \quad (5-1-13)$$

(U.S. Customary Units)

$$R_s^+ = \frac{1}{U^+} - R_m^+ - R_i^+ \times \left(\frac{d_o}{d_i} \right) - R_f^+ \quad (5-1-14)$$

5-2 CALCULATIONS FOR CONDENSER PRESSURE DEVIATION RESULTS

It is unlikely that the conditions during a performance test will ever exactly match the design conditions. As a result, comparison of the condenser shell pressure as measured by the performance test to the design value is not meaningful. Instead, it is first necessary to adjust the test results from the test conditions to the design-reference conditions. The correction procedures that follow are based on adjusting the test-calculated heat-transfer resistances for differences between the test and design conditions. These values are then used to compute the adjusted overall heat-transfer coefficient and the test-adjusted condenser steam pressure at the design-reference conditions.

The design-reference conditions are determined from manufacturer's data. Calculated values, not included with the data, are computed using the same procedures as developed in subsection 5-1, but substituting the design values for the test values.

5-2.1 Tube-Wall Resistance

The tube-wall resistance is a constant that is dependent only on the tube-wall thickness and material. Accordingly

$$R_m^* = R_m^+ \quad (5-2-1)$$

5-2.2 Tubeside Resistance

The tubeside thermal resistance shall be calculated at the design conditions as follows:

$$R_i^* = \left[0.0158 \times \frac{k^*}{D_i} \times (Re^*)^{0.835} \times (Pr^*)^{0.462} \right]^{-1} \quad (5-2-2)$$

where

$$Pr^* = \frac{1000 \times c_p^* \times \mu^*}{k^*} \quad (5-2-3)$$

$$Re^* = \frac{\rho^* \times v^* \times D_i}{\mu^*} \quad (5-2-4)$$

$$v^* = \frac{w^*}{3600 \times \rho^* \times \frac{N}{n} \times \frac{\pi}{4} \times D_i^2} \quad (5-2-5)$$

This equation is simplified for calculation in U.S. Customary units:

$$R_i^* = 0.0451 \times \left(\frac{\mu^{*0.373}}{k^{*0.538} \times \rho^{*0.835} \times c_p^{*0.462}} \right) \times \frac{d_i^{0.165}}{v^{*0.835}} \quad (5-2-6)$$

where

$$v^* = \frac{w^*}{25 \times \rho^* \times \frac{N}{n} \times \frac{\pi}{4} \times d_i^2} \quad (5-2-7)$$

Cooling-water fluid properties shall be evaluated at the average bulk water temperature, T_B^* , which is defined as

$$T_B^* = 0.5 \times (T_2^* + T_1^*) \quad (5-2-8)$$

5-2.3 Fouling Resistance

The manufacturer's design data usually express the fouling resistance in terms of a cleanliness factor. If the design-reference condenser pressure is based on a cleanliness factor of 1.0, the design fouling resistance, R_f^* , is equal to zero. For any other value of cleanliness factor, the resulting fouling resistance shall be determined as follows:

$$R_f^* = \frac{(1 - c_f^*)}{U^*} \quad (5-2-9)$$

where

$$U^* = \frac{Q^*}{A_o \times LMTD^*} \quad (5-2-10)$$

and

$$LMTD^* = \frac{(T_2^* - T_1^*)}{\ln \left(\frac{T_s^* - T_1^*}{T_s^* - T_2^*} \right)} \quad (5-2-11)$$

The saturation steam temperature, T_s^* , corresponding to pressure P_s^* shall be determined from the ASME Steam Tables [5].

5-2.4 Shellside Resistance

The shellside condensing heat transfer is the most complex component in the evaluation of a steam surface condenser. Numerous correlations of the Nusselt equation have been developed for the film coefficient for various condensing situations. These correlations are based on specific condensing conditions requiring a detailed

knowledge of the shell and tube nest geometries and the condensing conditions, and resulting in significantly different prediction values of the heat-transfer coefficient. As a result, the test value of the shellside resistance is determined in para. 5-1.6 based on the difference between the test-calculated overall heat-transfer coefficient and sum of the calculated values for the other heat-transfer resistances.

To adjust the shellside resistance value at the test conditions to the design condition, some formulation is necessary to correct for the difference in condensate film temperature between design condition and test condition. Because this requires an adjustment over a limited range of conditions, rather than a prediction of an absolute value of the shellside resistance, very precise predictions shall not be required.

$$R_s^o = R_s^+ \times \left(\frac{W_s^+}{W_s^*} \right)^{1/3} \times \left(\frac{\mu^+}{\mu^*} \right)^{1/3} \times \left(\frac{k^*}{k^+} \right) \times \left(\frac{\rho^*}{\rho^+} \right)^{2/3} \quad (5-2-12)$$

If the steam flow rate, W_s^+ , at the test conditions is not available, the expression $\frac{W_s^+}{W_s^*}$ should be substituted with $\frac{Q^+}{Q^*}$. The liquid properties shall be evaluated at the bulk average temperature of the condensate film. This temperature shall be approximated as follows:

$$T_f^* = T_s^* - 0.2 \times LMTD^* \quad (5-2-13)$$

and

$$T_f^+ = T_s^+ - 0.2 \times LMTD^+ \quad (5-2-14)$$

5-2.5 Overall Heat-Transfer Coefficient

The overall heat-transfer coefficient, U , which is adjusted to the design-reference conditions, shall be calculated as follows: determined by difference as follows:

(SI Units)

$$U^o = \frac{1}{R_m^* + R_i^* \times \left(\frac{D_o}{D_i} \right) + R_f^* + R_s^o} \quad (5-2-15)$$

(U.S. Customary Units)

$$U^o = \frac{1}{R_m^* + R_i^* \times \left(\frac{d_o}{d_i} \right) + R_f^* + R_s^o} \quad (5-2-16)$$

5-2.6 Adjusted Test Condenser Steam Pressure

The test condenser steam pressure, which is adjusted to the design-reference conditions, shall be determined using the following equation:

$$NTU^o = \frac{C \times U^o \times A^*}{c_p^* \times w^*} \quad (5-2-17)$$

where

$C = 3.6$ for SI units

$C = 1$ for U.S. Customary units

$$T_s^o = \frac{T_2^* - T_1^* \times e^{-NTU^o}}{(1 - e^{-NTU^o})} \quad (5-2-18)$$

The adjusted steam pressure, P_s^o , corresponding to the saturation steam temperature, T_s^o , as calculated from eq. (5-2-18) shall be determined from ASME Steam Tables [5].

5-2.7 Evaluation of Results Acceptance

The difference between the test-adjusted and design-reference steam pressures shall be evaluated as follows:

$$\Delta P_s = P_s^* - P_s^o \quad (5-2-19)$$

If the pressure difference is greater than or equal to zero, the condenser performance is satisfactory and considered acceptable. If the pressure difference is less than zero, the condenser performance is worse than specified and is considered unacceptable.

5-2.8 Multipressure Condensers

Multipressure condenser performance shall be assessed separately for each pressure compartment. There are two types of multipressure condensers: the multiple-shell multipressure condenser (Fig. 5-2.8-1) and the single-shell multipressure condenser (Fig. 5-2.8-2).

5-2.8.1 Condenser Heat Load. The turbine-exhaust steam flows shall be assumed to be equally divided between each of the multipressure compartments. If other major steam loads are present in a particular compartment, such as from a boiler feed pump turbine, then that estimated value shall be added to the compartment heat load.

For multipressure condensers, the cooling-water temperature between compartments cannot be measured due to temperature stratification or inaccessibility. The temperature can be estimated by assuming that the temperature rise is proportional to the heat load in each compartment. The calculation procedure shall be as follows:

$$\Delta t(\text{measured}) = \Delta T_x + \Delta T_y + \Delta T_z \quad (5-2-20)$$

where

$$\Delta T_x = (\Delta t) \left(\frac{Q_x}{Q} \right)$$

$$\Delta T_y = (\Delta t) \left(\frac{Q_y}{Q} \right)$$

$$\Delta T_z = (\Delta t) \left(\frac{Q_z}{Q} \right)$$

NOTE: A three-compartment condenser is used for illustration in Figs. 5-2.8-1 and 5-2.8-2, but the procedure also applies to two-compartment multipressure condensers.

5-2.8.2 Overall Heat-Transfer Coefficient. The overall heat-transfer coefficient at the test condition for each compartment shall be calculated using the method outlined in para. 5-1.2.

5-2.8.3 Tube-wall Resistance. The tube-wall resistance shall be calculated using the method in para. 5-1.3.

5-2.8.4 Tubeside Resistance. The tubeside resistance shall be calculated using the method in para. 5-1.4.

5-2.8.5 Shellside Resistance. The shellside resistance for each compartment shall be calculated using the method in para. 5-1.6.

5-2.8.6 Condenser Pressure Deviation Results Calculation. The condenser pressure deviation results calculation for each compartment shall be the same as that for the single-pressure condenser, as outlined in subsection 5-2. The cooling-water temperature between compartments shall be estimated using the method outlined in para. 5-2.8.1.

5-3 CALCULATIONS OF RESULTS DEVIATIONS FOR OTHER PARAMETERS

5-3.1 Acceptance Criterion for Tubeside Pressure-Drop Deviation Calculations

The test-measured tubeside pressure drop shall be adjusted for differences between the test and design-reference water flow rates as follows:

$$\Delta P_t^o = \Delta P_t^+ \left(\frac{w^*}{w^+} \right)^{1.8} \quad (5-3-1)$$

If the calculated tubeside pressure drop is less than or equal to the design value, this aspect of the condenser performance is satisfactory and is considered acceptable. If it is greater than the design value, this aspect of the condenser performance is worse than specified and is unacceptable.

5-3.2 Calculation of Condensate Subcooling Results

$$\Delta T_s^+ = T_s^+ - T_3^+ \quad (5-3-2)$$

If the calculated condensate subcooling at test conditions is less than or equal to design value, this aspect of the condenser performance is satisfactory and considered acceptable. If it is greater than the design value, the condenser performance is worse than specified and is considered unacceptable.

5-3.3 Acceptance Criterion for Dissolved-Oxygen Calculations

The dissolved oxygen test result shall be determined by averaging the measured dissolved-oxygen results at the specified time intervals for each condenser outlet pipe. If the averaged result is greater than the dissolved-oxygen design value for any condensate outlet, the condenser performance is worse than specified and is considered unacceptable.

Fig. 5-2.8-1 Multiple-Shell Multipressure Condenser

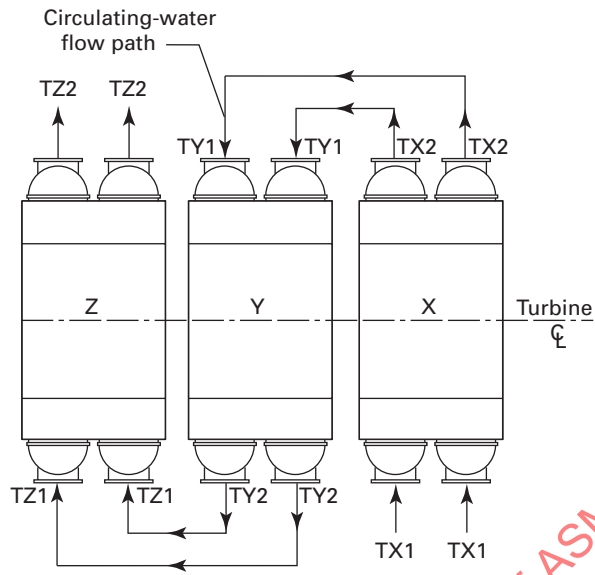
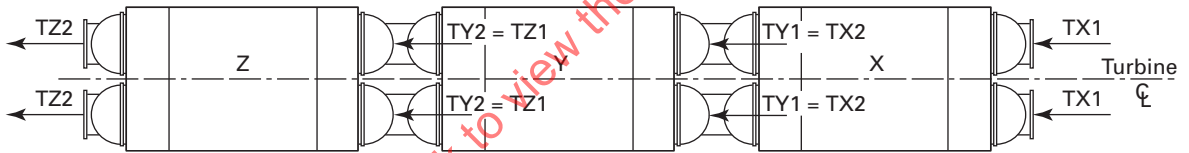


Fig. 5-2.8-2 Single-Shell Multipressure Condenser



Section 6

Report of Results

6-1 COMPOSITION OF REPORT

The report of the results of the test shall include as a minimum the following:

- (a) a brief summary of the objective, results, and conclusions
- (b) a list of the representative parties to the test
- (c) a description of the condenser tested
- (d) a description of the thermal design conditions of the condenser
- (e) the method of the test (including a sketch of the cooling tower and test instrument locations) including, but not limited to, the following:
 - (1) overall dimensions of the installation
 - (2) piping and riser layout
 - (3) water flow rate and temperature-measurement locations
 - (4) types of instruments used
 - (5) description of any methods of measurement not prescribed by the Code
- (f) a summary of measurements and observations
- (g) the methods of calculation from obtained data
- (h) the specified or agreed-upon allowances for possible error, including method of application
- (i) test results reported as follows:
 - (1) results, presented in tabular and graphical form, computed on the basis of the operating conditions

during test; only correction applied shall be for instrument calibrations

- (2) results, presented in tabular and graphical form, corrected to specified conditions if the operating conditions during the test deviated from those specified
- (j) discussion of the test, its results, and conclusions
- (k) supporting documentation or information required to make the report complete, such as
 - (1) appendices and illustrations to clarify description of the equipment, methods, and circumstances of the test
 - (2) descriptions of methods of calibration of the test instruments, as well as calibration certificates
 - (3) sample test-result calculations
 - (4) data sheets and applicable performance curves
 - (5) raw data as recorded during the test
 - (6) calibration checks performed on-site

6-2 REPORT DATA

Copies of the final test report shall be distributed to the test parties. Tests performed by independent agencies shall not be distributed beyond the official parties to the test.

NONMANDATORY APPENDIX A ALTERNATIVE TEST

A-1 INTRODUCTION

This Appendix describes the alternative test. The alternative test is more accurate because it includes an evaluation of the existing fouling level of the condenser; however, it is significantly more elaborate, time consuming, and costly.

Most aspects of the test apply to the alternative test and so are not repeated in this Appendix; only sections that are uniquely particular to the alternative test are specified. The areas to be addressed in this Appendix are

- (a) the pairs of tubes that are selected for the fouling evaluation
- (b) the additional instrumentation required by the fouling test
- (c) the fouling measurements and fouling data reduction using a relative heat transfer for each pair and the use of the results in the overall condenser performance guarantee calculations

Agreement shall be reached on the method and data for initial pretest uncertainty analysis and post-test uncertainty analysis calculation.

Excessive air in-leakage often degrades the condenser performance and increases the concentration of dissolved oxygen in the condensate. The air removal rate must be within the limits of Table A-1-1 because it directly impacts the condenser heat-transfer capability. To ensure that the performance of the condenser has not been impaired prior to the test, the noncondensable gas load shall be measured to confirm adherence to the guideline in Table A-1-1. Techniques for measuring noncondensable gas load are given in ASME PTC 19.5 [1]. Proper functioning of all air-removal equipment should be verified prior to the test.

More specifically, the alternative test requires a determination of the condenser tube-bundle fouling. The measurement is necessary to adjust the condenser's overall heat-transfer coefficient as determined by the test results to design or guarantee conditions. The fouling test consists of a measurement of the outlet temperatures of sets of two adjacent tubes. One of the tubes of each set remains in the as-found fouled condition, while the neighboring tube is either cleaned or replaced with a new tube. As required, the condenser

undergoes a general cleaning immediately prior to the test. Otherwise, the tube pair experiences identical heat-transfer conditions, that is, steam pressures, cooling-water flow rates, and velocities. The outlet temperature measurements provide a comparison of the heat-transfer rates of the tube pairs, and, consequently, the fouling resistance of the bundle.

A-2 MEASUREMENT LOCATIONS

The number of pairs of tubes selected for the fouling test shall be 1 per 2,000 tubes per tube bundle, but not fewer than 4 pairs or more than 16 pairs per bundle. The pairs shall be located at the approximate centroids of equal tube sectors within the tube-bundle pattern. However, pairs should not be placed within three tube rows of the bundle periphery due to the atypical conditions there. The number of pairs per number of tubes shall be the same regardless of whether the condenser is a single-pass, two-pass, or multipressure type. When testing multipass surface condensers, the water temperatures at the return waterbox are required for comparison with water temperatures of the adjacent tubes. For the pairs of tubes located at the water return pass, the fouling resistances should also be calculated and considered as additional data when averaging R_f^+ according to the eq. (A-7-1). For these pairs, R_{fi}^+ should be calculated taking into account that, in these cases, T_1 is measured at the return waterbox and T_2 at the outlet waterbox.

See the discussion of multipressure condensers in subsection A-9 for recommendations on the measurement of fouling for that particular design.

A-3 TEST CONDITIONS AND MEASUREMENTS

The test shall be conducted immediately before, during, or after the condenser heat-transfer test, as is convenient. In addition to the outlet temperature, the cooling-water flow, inlet temperatures, and condenser pressures shall be measured. The measurement, calibration, test conditions, and limitations of these parameters shall comply in all respects to all the related requirements listed in this Appendix and Table 3-4-2. A minimum of four sets of readings spanning 30 min shall constitute a test.

Table A-1-1 Noncondensable Gas Load (Air In-Leakage Limits)

SI Units		
Number of Shells	Total Exhaust Steam Flow, kg/hr	Noncondensable Gas Load Limit, slpm
1	Up to 45 351.5	28
1	45 351.5–113 378.7	57
1	113 378.7–226 757.4	71
1	226 757.4–453 514.7	85
1	453 514.7–907 029.5	106
1	907 029.5–1 360 544.2	127
1	1 360 544.2–1 814 059	142
2	90 703–226 757.4	99
2	226 757.4–453 514.7	113
2	453 514.7–907 029.5	106
2	907 029.5–1 814 059	127
2	1 814 059–2 721 088.4	149
2	2 721 088.4–3 628 117.9	170
3	340 136.1–1 360 544.2	127
3	1 360 544.2–3 628 117.9	170
3	3 628 117.9–4 081 632.7	198
3	4 081 632.7–5 442 176.9	226

U.S. Customary Units		
Number of Shells	Total Exhaust Steam Flow, lb/hr	Noncondensable Gas Load Limit, scfm
1	Up to 100,000	1.0
1	100,000–250,000	2.0
1	250,000–500,000	2.5
1	500,000–1,000,000	3.0
1	1,000,000–2,000,000	3.75
1	2,000,000–3,000,000	4.5
1	3,000,000–4,000,000	5.0
2	200,000–500,000	3.5
2	500,000–1,000,000	4.0
2	1,000,000–2,000,000	3.75
2	2,000,000–4,000,000	4.50
2	4,000,000–6,000,000	5.25
2	6,000,000–8,000,000	6.00
3	750,000–3,000,000	4.50
3	3,000,000–6,000,000	6.00
3	6,000,000–9,000,000	7.00
3	9,000,000–2,000,000	8.00

A-4 OUTLET TEMPERATURE INSTALLATION

A-4.1 Outlet Temperature Where Stratification Is a Concern

If possible, measurement of the discharge temperature should be made far downstream from the condenser where the discharge is well mixed and the temperature is uniform. This location shall be considered acceptable if the cooling-water discharge from the unit under test does not mix with any other significant flows, and if it can be shown that the heat loss from the discharge pipe to the environment is less than 0.2% of the condenser duty, and if it can be determined that no stratification exists. The latter requirement should be met by making at least five temperature measurements along a single vertical traverse, and verifying that there are no temperature differences greater than 0.11°C (0.2°F) or 1% of the average temperature rise across the condenser, whichever is greater. The temperature measurement for testing should be made by either inserting a probe directly into the flow, or using a thermowell as described in para. 4-4.1.

A-4.2 Outlet Temperature for Fouling Test

For the fouling test, a temperature sensor shall be installed at the outlets of each of the tubes in a manner that ensures tube blockage is minimized and an accurate discharge temperature is measured. The installation shall be sufficiently rugged and suitably waterproofed to withstand the hydraulic forces and temperatures of the discharged cooling water. The temperature-sensor lead wire from the sampled tubes shall be routed and secured between the tube holes on the outlet tube sheet. They shall be bundled and fed out through a new or existing waterbox penetration to the readout.

In the case of two-pass or multipressure condensers in separate shells, tube pairs located in the bundle subsequent to the first shall have an inlet temperature measurement similar to that described for the outlet sensor.

Since the variety of installation situations will be numerous, only general guidance on affixing the sensor to the tube sheet can be provided, as follows:

- If an outlet tube stub exists, plastic collars should be utilized as shown in Nonmandatory Appendix F.
- Direct attachment to the tube sheet shall be permissible as long as the sensor extends into the flow.
- Attachment of a suitable minimal blockage fixture into the tube interior that holds the sensor shall also be permitted if it can be demonstrated that the total added blockage is less than 5% of the internal tube flow area.

A-5 TUBE TEMPERATURE RISES

Tube temperature rises for the fouling tests shall be measured in general accordance with the procedures described in this Section. RTDs or thermocouples may be

used, provided that the uncertainty of the temperature measurement system is at most 0.1. If thermocouples are used, a direct differential temperature measurement setup should be used. If RTDs are used, the pairs of RTDs that will be used on the monitored tubes should be calibrated together to minimize the effect of any bias errors in the calibration on the determination of the temperature difference between the paired RTDs. Provision shall be made for calibration of the temperature measurement devices before and after the fouling test, over the expected range of temperature differences and within 2.8°C (5°F) of the expected inlet-water temperature. Following the fouling test, all instrumented tubes shall be inspected to ensure that they are clear and have not been influenced by blockage or any other factor (other than tube fouling) that may affect the results.

A-6 CONDENSER HEAT-TRANSFER RESISTANCES

Except for the measured fouling resistance and numerical determination of the shellside resistance, all other resistances shall be measured as described in the Test Code.

A-7 FOULING RESISTANCE

The fouling resistance shall be determined from comparison of adjacent tubes. For j pairs of tubes, the fouling resistance, R_f is determined by

$$R_f^+ = \frac{1}{j} \sum_{i=1}^j R_{fi}^+ \quad (\text{A-7-1})$$

where the fouling resistance for each tube pair is determined from

$$R_{fi}^+ = \frac{C \times A}{n \times w^+ \times c_p^+} \times \left[\frac{1}{\ln \left(\frac{T_s^+ - T_{1,fi}^+}{T_s^+ - T_{2,fi}^+} \right)} - \frac{1}{\ln \left(\frac{T_s^+ - T_{1,ci}^+}{T_s^+ - T_{2,ci}^+} \right)} \right] \quad (\text{A-7-2})$$

where

$C = 3.6$ for SI units

$C = 1$ for U.S. Customary units

A-8 SHELLSIDE RESISTANCE

The shellside resistance at the test conditions shall be determined by difference as follows:

(SI Units)

$$R_s^+ = \frac{1}{U^+} - R_m^+ - R_t^+ \times \left(\frac{D_o}{D_i} \right) - R_f^+ \quad (\text{A-8-1})$$

(U.S. Customary Units)

$$R_s^+ = \frac{1}{U^+} - R_m^+ - R_t^+ \times \left(\frac{d_o}{d_i} \right) - R_f^+ \quad (\text{A-8-2})$$

A-9 MULTIPRESSURE CONDENSERS

A-9.1 Fouling Resistance

The fouling resistance for multipressure condensers shall be determined from comparison of adjacent tubes, in the same manner as for a single-pressure condenser. For j pairs of tubes, the fouling resistance, $R_{f,p}$ for each pressure compartment shall be determined by

$$R_{f,x} = \frac{1}{j} \sum R_{f,x,i}$$

$$R_{f,y} = \frac{1}{j} \sum R_{f,y,i}$$

$$R_{f,z} = \frac{1}{j} \sum R_{f,z,i}$$

In a multiple-shell multipressure condenser, the cooling-water outlet temperatures from each compartment shall be measured and the results used in the calculation of the fouling resistance. For single-shell multipressure condensers, the cooling-water temperature between compartments cannot be measured. These temperatures shall instead be estimated using the same procedure as outlined in para. 5-2.8.

$$Q = Q_x + Q_y + Q_z$$

$$\Delta t_{f,i(\text{measured})} = \Delta T_{f,x,i} + \Delta T_{f,y,i} + \Delta T_{f,z,i}$$

$$\Delta T_{f,x,i} = (\Delta t_{f,i}) \left(\frac{Q_x}{Q} \right)$$

$$\Delta T_{f,y,i} = (\Delta t_{f,i}) \left(\frac{Q_y}{Q} \right)$$

$$\Delta T_{f,z,i} = (\Delta t_{f,i}) \left(\frac{Q_z}{Q} \right)$$

$$T_{f,2,i} = t_1 + \Delta T_{f,x,i}$$

$$T_{f,3,i} = t_{f,2,i} + \Delta T_{f,y,i}$$

$$T_{f,4,i} = t_{f,3,i} + \Delta T_{f,z,i}$$

$$\Delta t_{c,i(\text{measured})} = \Delta T_{c,x,i} + \Delta T_{c,y,i} + \Delta T_{c,z,i}$$

$$\Delta T_{c,x,i} = (\Delta t_{c,i}) \left(\frac{Q_x}{Q} \right)$$

$$\Delta T_{c,y,i} = (\Delta t_{c,i}) \left(\frac{Q_y}{Q} \right)$$

$$\Delta T_{c,z,i} = (\Delta t_{c,i}) \left(\frac{Q_z}{Q} \right)$$

$$T_{c,2,i} = t_1 + \Delta T_{c,x,i}$$

$$T_{c,3,i} = t_{c,2,i} + \Delta T_{c,y,i}$$

$$T_{c,4,i} = t_{c,3,i} + \Delta T_{c,z,i}$$

where

subscript 4 = the outlet of the high-pressure compartment

$$R_{fxi} = \frac{C \times A_x}{w \times c_p} \times \left[\frac{1}{\ln \left(\frac{T_{s,x} - T_1}{T_{s,x} - T_{f,2,i}} \right)} - \frac{1}{\ln \left(\frac{T_{s,x} - T_1}{T_{s,x} - T_{c,2,i}} \right)} \right]$$

$$R_{fyi} = \frac{C \times A_y}{w \times c_p} \times \left[\frac{1}{\ln \left(\frac{T_{s,y} - T_{f,2,i}}{T_{s,y} - T_{f,3,i}} \right)} - \frac{1}{\ln \left(\frac{T_{s,y} - T_{c,2,i}}{T_{s,y} - T_{c,3,i}} \right)} \right]$$

$$R_{fzi} = \frac{C \times A_z}{w \times c_p} \times \left[\frac{1}{\ln \left(\frac{T_{s,z} - T_{f,3,i}}{T_{s,z} - T_{f,4,i}} \right)} - \frac{1}{\ln \left(\frac{T_{s,z} - T_{c,3,i}}{T_{s,z} - T_{c,4,i}} \right)} \right]$$

where

$C = 3.6$ for SI units

$C = 1$ for U.S. Customary units

A-9.2 Shellside Resistance

The shellside resistance for each multipressure compartment shall be calculated in the manner described in subsection A-8.

A-10 UNCERTAINTY ANALYSIS

To determine if a test conducted in accordance with these procedures meets the uncertainty criteria specified in subsection 1-3, an estimate of the standard uncertainty in the test results attributable to measurement uncertainties shall be performed as part of the test calculations.

The following nomenclature applies to this subsection:

b_j = the systematic error for parameter j

F = recurring subject partial derivative within sensitivity-factor equations

S_j = the precision index for parameter j

t_v = the Student's t -statistic, determined from tabular data for the degrees of freedom, v , and a 95% coverage, per Fig. A-10-1

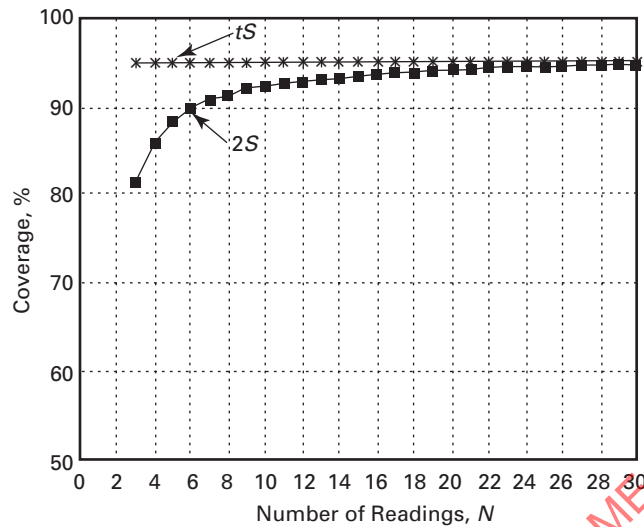
Un_{P_s} = the overall uncertainty in the test-adjusted steam pressure at a 95% coverage

$Un_{\Delta P_w}$ = the overall uncertainty in the test-adjusted tubeside pressure drop at a 95% coverage

v_j = the degrees of freedom for parameter j , used in evaluating the precision error estimate

θ_j = the sensitivity factor for parameter j

Fig. A-10-1 Percent Coverage per Number of Readings



The following recommended instrument specification provides the lowest level of uncertainty for condenser pressure measurement:

Instrument	Electronic absolute-pressure transducer
Type	Isolated sensor
Range	0 kPa to 120 kPa (0 in. HgA to 35.4 in. HgA)
Accuracy	±0.02 full scale
Uncertainty	±0.07 kPa (±0.02 in. HgA) max.

Other instrument uncertainties should be as follows:

Inlet-water temperature	±0.1°F
Outlet-water temperature	±0.2°F
Cooling-water flow (% of reading)	±2.0%
Tube-bundle pressure loss (% of reading)	±2%
Air in-leakage	±2.0 scfm

The actual test uncertainty for the alternative test shall be determined by a specific post-test uncertainty analysis described in this Appendix.

A-10.1 Standard Uncertainty in Test-Adjusted Steam Pressure

An estimate of the standard uncertainty in the test steam pressure, adjusted to the design-reference conditions, shall be calculated as follows:

$$Un_{P_{s^o}} = \sqrt{b_{P_{s^o}}^2 + s_{P_{s^o}}^2}$$

where

$$b_{P_{s^o}}^2 = \theta_{w_s^+}^2 b_{w_s^+}^2 + \theta_{w^+}^2 b_{w^+}^2 + \theta_{p_s^+}^2 b_{p_s^+}^2 + \theta_{T_1^+}^2 b_{T_1^+}^2 + \theta_{T_2^+}^2 b_{T_2^+}^2 + \theta_{T_{1,f}^+}^2 b_{T_{1,f}^+}^2 + \theta_{T_{2,f}^+}^2 b_{T_{2,f}^+}^2 + \theta_{T_{1,c}^+}^2 b_{T_{1,c}^+}^2 + \theta_{T_{2,c}^+}^2 b_{T_{2,c}^+}^2$$

and

$$s_{P_{s^o}}^2 = \theta_{w_s^+}^2 s_{w_s^+}^2 + \theta_{w^+}^2 s_{w^+}^2 + \theta_{p_s^+}^2 s_{p_s^+}^2 + \theta_{T_1^+}^2 s_{T_1^+}^2 + \theta_{T_2^+}^2 s_{T_2^+}^2 + \theta_{T_{1,f}^+}^2 s_{T_{1,f}^+}^2 + \theta_{T_{2,f}^+}^2 s_{T_{2,f}^+}^2 + \theta_{T_{1,c}^+}^2 s_{T_{1,c}^+}^2 + \theta_{T_{2,c}^+}^2 s_{T_{2,c}^+}^2$$

The methodology and procedures for estimating the systematic and random standard uncertainties for each of the independent measurement parameters are provided in ASME PTC 19.1 [1] and are therefore not repeated here. Also note that when measurements share elemental error sources, correlation exists and shall be accounted for. This correlation should be resolved in accordance with the procedures outlined in ASME PTC 19.1 [1]; however, these procedures are beyond the scope of the current Code.

A-10.2 Sensitivity Coefficients

The sensitivity coefficients, θ , used in the formulations in para. A-10.1 should be calculated analytically using partial differentiation or numerically using one of many techniques. The sensitivity coefficients are shown below for purposes of illustration and would be calculated analytically making use of the chain rule. Because of the complexity of the relationships, however, the central difference method should instead be employed with separate perturbations of the individual instrument uncertainties. That is, using the condenser data-reduction equations and procedures given previously in this Section, compute the average test result from the average test data. Then, using the same equations, systematically compute the change in the final test result caused by a small change in each of the input test variables. This overall resulting uncertainty shall be applied to the design-reference steam pressure, subcooling, dissolved oxygen, and tubeside pressure drop. Note that

the uncertainties associated with property variations are neglected due to the small magnitudes of these uncertainties in comparison to the total standard uncertainty. Accordingly, sensitivity coefficients for the fluid properties were not calculated.

(a) Sensitivity coefficient for steam flow rate

$$\theta_{w_s^+} = \frac{\partial P_s^o}{\partial w_s^+}$$

(b) Sensitivity coefficient for cooling-water flow rate

$$\theta_{w^+} = \frac{\partial P_s^o}{\partial w^+}$$

(c) Sensitivity coefficient for steam pressure

$$\theta_{p_s^+} = \frac{\partial P_s^o}{\partial P_s^+}$$

(d) Sensitivity coefficient for inlet-water temperature

$$\theta_{T_1^+} = \frac{\partial P_s^o}{\partial T_1^+}$$

(e) Sensitivity coefficient for outlet-water temperature

$$\theta_{T_2^+} = \frac{\partial P_s^o}{\partial T_2^+}$$

(f) Sensitivity coefficient for inlet-water temperature of the fouled tube

$$\theta_{T_{1,f}^+} = \frac{\partial P_s^o}{\partial T_{1,f}^+}$$

(g) Sensitivity coefficient for outlet-water temperature of the fouled tube

$$\theta_{T_{2,f}^+} = \frac{\partial P_s^o}{\partial T_{2,f}^+}$$

(h) Sensitivity coefficient for inlet-water temperature of the clean tube

$$\theta_{T_{1,c}^+} = \frac{\partial P_s^o}{\partial T_{1,c}^+}$$

(i) Sensitivity coefficient for outlet-water temperature of the clean tube

$$\theta_{T_{2,c}^+} = \frac{\partial P_s^o}{\partial T_{2,c}^+}$$

A-10.3 Standard Uncertainty in Tubeside Pressure Drop

The standard uncertainty in the tubeside pressure drop adjusted to the design-reference conditions shall be calculated as follows:

$$Un_{\Delta P_t^o} = \sqrt{b_{\Delta P_t^o}^2 + S_{\Delta P_t^o}^2}$$

where

$$b_{\Delta P_t^o}^2 = \theta_{\Delta P_t^+}^2 b_{\Delta P_t^+}^2 + \theta_{w^+}^2 b_{w^+}^2$$

and

$$S_{\Delta P_t^o}^2 = \theta_{\Delta P_t^+}^2 S_{\Delta P_t^+}^2 + \theta_{w^+}^2 S_{w^+}^2$$

The sensitivity coefficients are calculated as follows:

$$\theta_{\Delta P_t^+} = \frac{\partial \Delta P_t^o}{\partial \Delta P_t^+}$$

and

$$\theta_{w^+} = \frac{\partial \Delta P_t^o}{\partial w^+}$$

A-10.4 Standard Uncertainty in the Condensate Subcooling

The standard uncertainty in the condensate subcooling shall be calculated as follows:

$$Un_{\Delta T_s^+} = \sqrt{b_{\Delta T_s^+}^2 + S_{\Delta T_s^+}^2}$$

where

$$b_{\Delta T_s^+}^2 = \theta_{T_s^+}^2 b_{\Delta T_s^+}^2 + \theta_{T_c^+}^2 b_{T_c^+}^2$$

and

$$S_{\Delta T_s^+}^2 = \theta_{T_s^+}^2 S_{T_s^+}^2 + \theta_{T_c^+}^2 S_{T_c^+}^2$$

The sensitivity coefficients for the steam temperature and condensate temperature at test conditions are equal to 1 and -1, respectively.

A-10.5 Standard Uncertainty in Dissolved Oxygen in Condensate

The standard uncertainty in the dissolved oxygen in the condensate shall be calculated as follows:

$$Un_{DO_2^+} = \sqrt{b_{DO_2^+}^2 + S_{DO_2^+}^2}$$

In general, a data acquisition system should be utilized for data-logging purposes. Using this type of system allows the logging of a large number of data points over a period of time prescribed by the experimentalist. However, under the circumstances where the logging of many data points is not possible, the Student's t factor may be useful ($N < 10$). A table of Student's t factors can be found in many statistical handbooks where the number of degrees of freedom is taken as one less than the number of measurements ($N - 1$). Fig. A-10-1 shows the percent coverage as the number of measurement increases. The Student's t factor can be approximated as 2 when the number of measurements is greater than 10.

NONMANDATORY APPENDIX B FLOWCHARTS AND CHECKLISTS

To guide users of the Code in the instrumentation selection and preparation process, the flowcharts in Figs. B-1, B-2, and B-3 and checklists in Forms B-1 and B-2 have been created. These will help the user properly plan all necessary stages of the test. They should be generalized to fit individual needs. These aids should not be substituted for a site-specific test plan, instrumentation list, required calibration

methods, or any other mutually agreed-upon testing procedure.

Under no circumstances should these aids limit or confine the user. If a more comprehensive testing plan is necessary, it is up to the testing parties to produce a document that is mutually inclusive in all areas of importance. This Appendix can serve as a starting point for such an undertaking (see Forms B-1 and B-2).

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Fig. B-1 Test Plan Flowchart

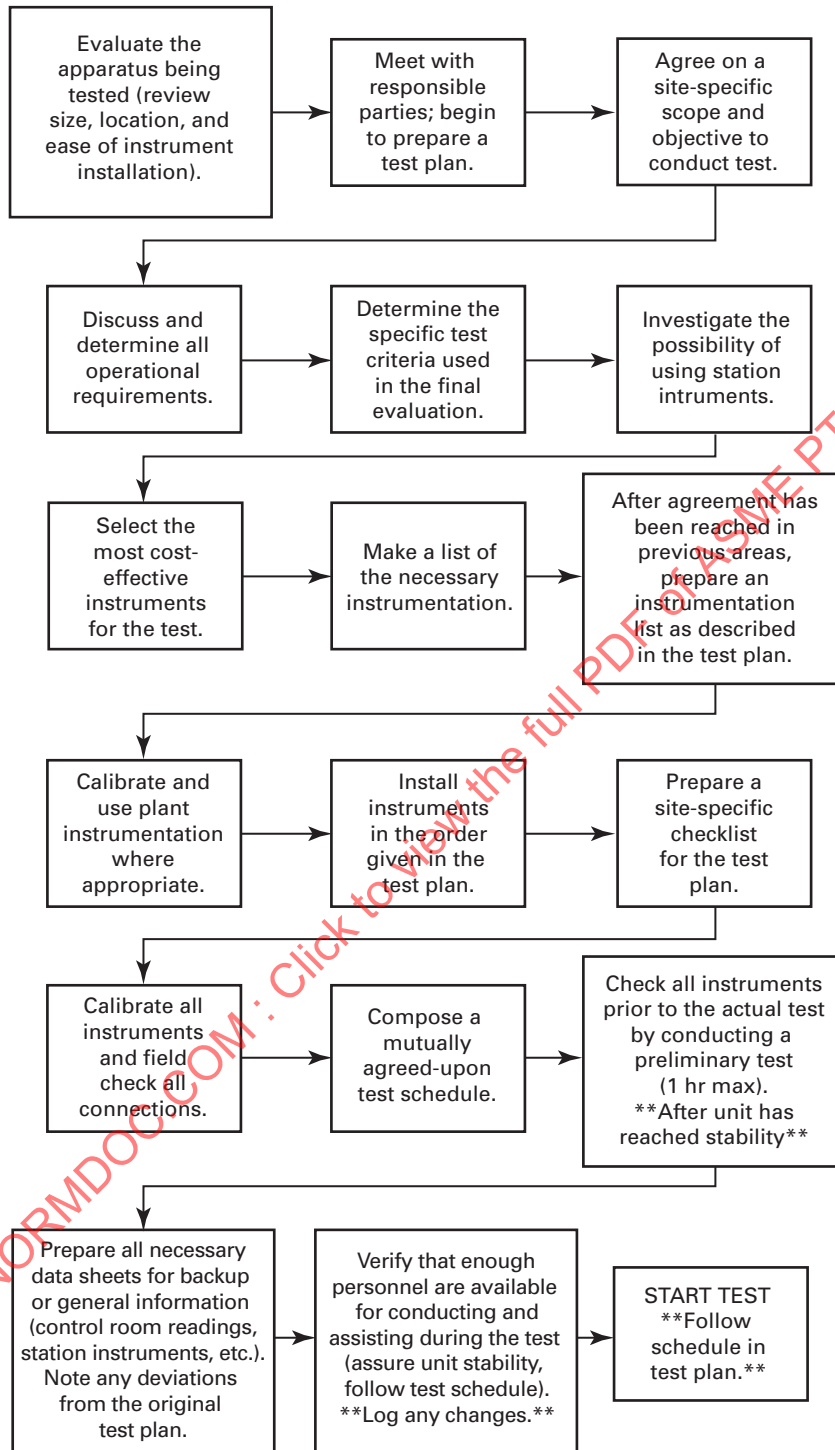


Fig. B-2 Selection of Measurement Devices for Cooling-Water Flow

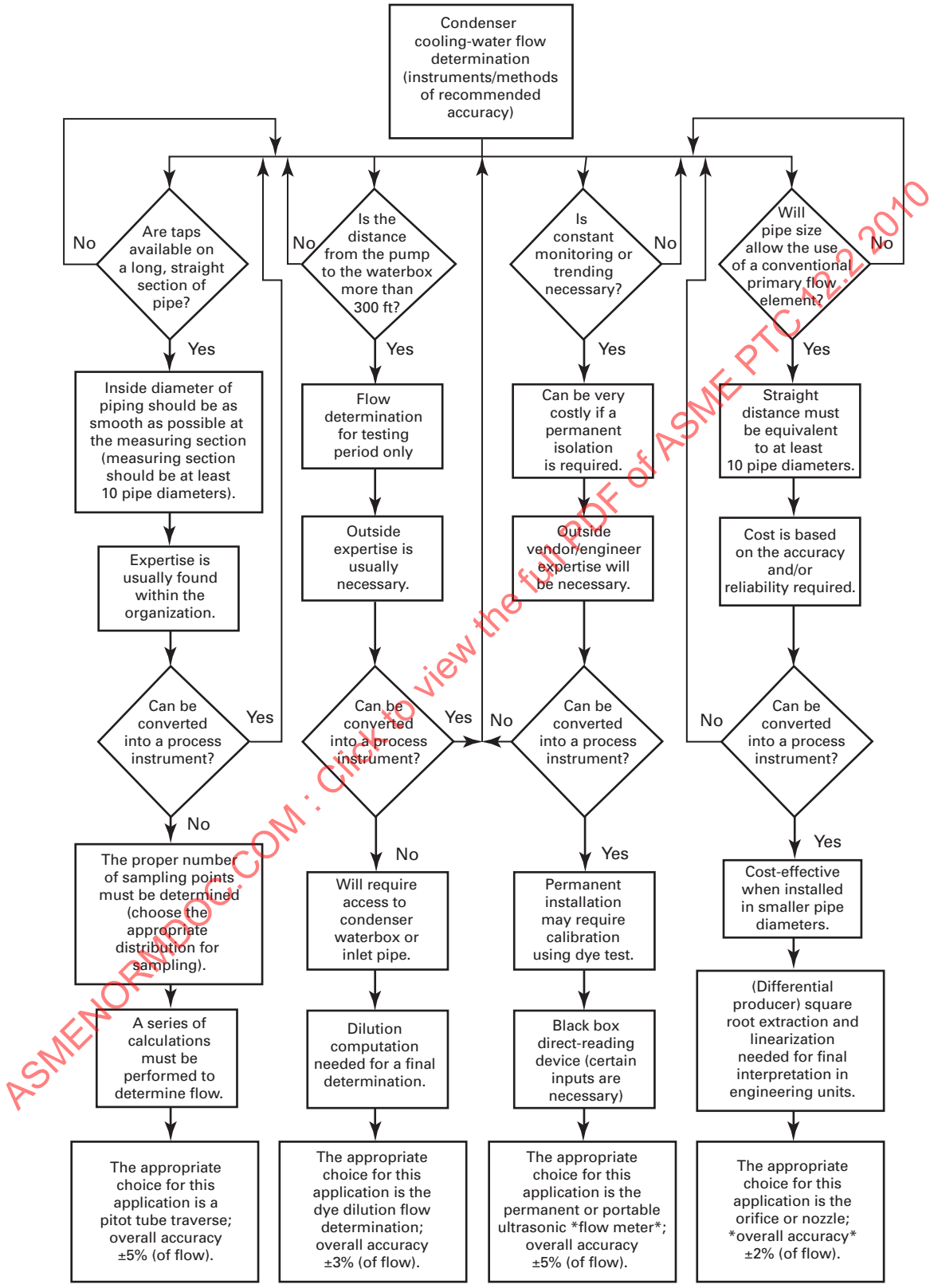
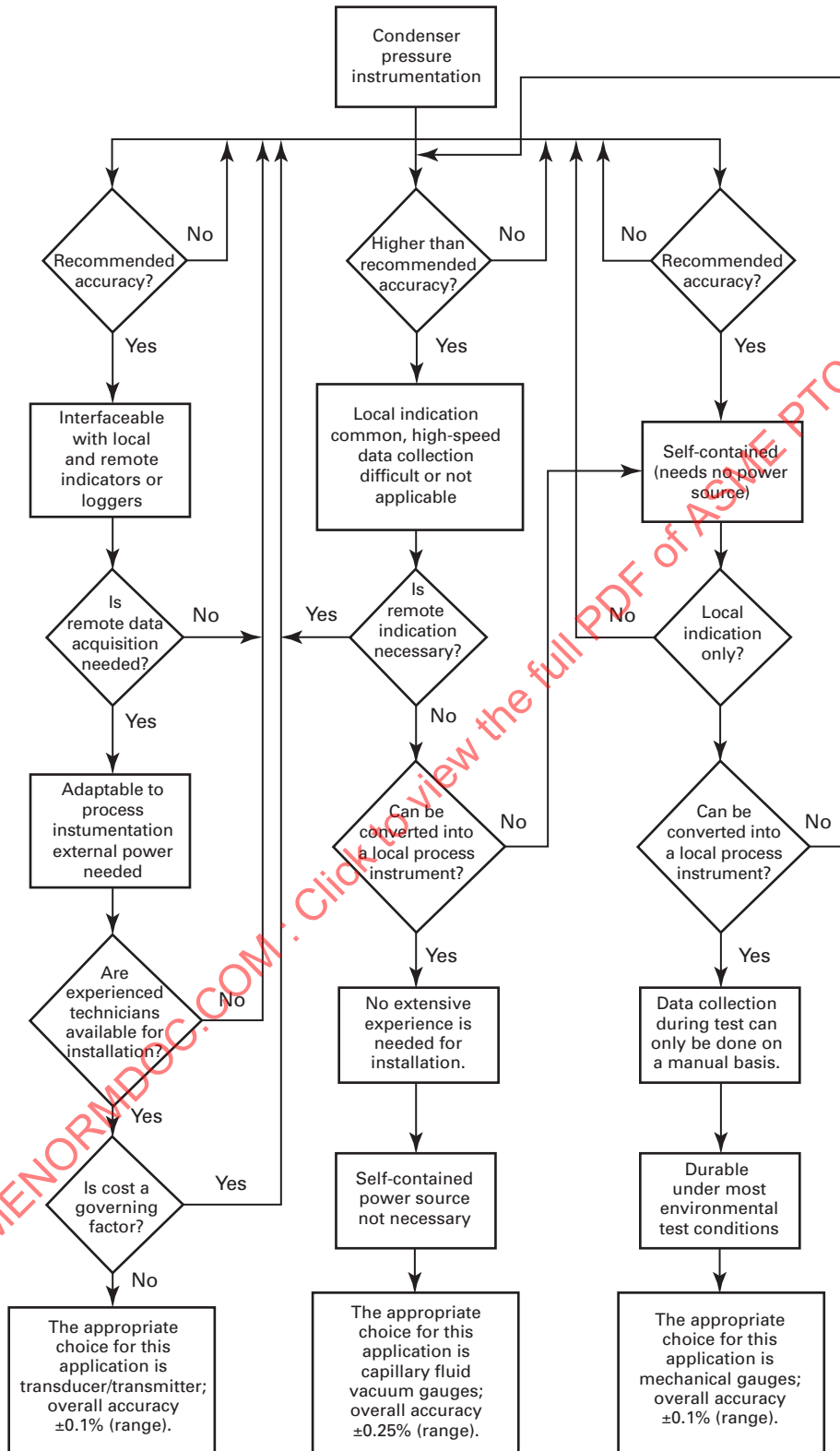


Fig. B-3 Selection of Pressure-Measurement Devices



Form B-1 Test Lab Instrumentation Checklist

Parameter Tested	Instrument Used	Expected Accuracy	Calibration Range	Location	Value

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Form B-2 Test Plan Checklist

Test Method		Activity
The Test	Alternative Test	
X	X	Determine the overall scope of the test. Evaluate the specific parameters that need to be tested.
X	X	Select the most cost-effective instruments and/or methods to measure all of the necessary parameters.
	X	Perform a pretest uncertainty analysis regarding the parameters to be measured.
	X	Install instruments in a sensible order. Begin with the pressure instruments. Calibrate the pressure instruments at their respective locations to compensate for environmental changes.
X		Identify the pressure instruments to be used. Confirm that they are within calibration.
	X	Install all temperature instruments in a logical order. Run extension wire or cable back to data-logging device (where appropriate).
X		Identify the temperature instruments to be used. Confirm that they are within calibration.
X	X	Check logging device for operation, including a continuity check on all the test parameters.
X	X	Inspect the installation. Ensure that there are no open circuits or faulty ground loops.
X	X	When all channels of the data logger (if used) are properly working, begin pressure calibration.
X	X	Check all local instruments for proper operation (thermocouple gauges, transducers, etc.). Calibrate where appropriate.
X	X	Verify that all calibrations are clearly recorded and traceable to an accepted standard.
X	X	Check for measurement feasibility by logging all pressures, flows, and temperatures at the operational conditions.
X	X	Where the plant information (PI) system is used, prepare a report that contains all the relevant pressures, flows, and temperatures, and save or print a few minutes' data.
X	X	Correct any problems with instruments, loggers, PI interface, and associated hardware.
X	X	Prepare a test schedule with all test and operating parties. Include start and stop times, unit load or steam, flow, operating requirements, and any other pertinent information regarding the operation of the condenser. Incorporate these into a logical and achievable test schedule.
X	X	Conduct a preliminary test as close to the agreed-upon operational requirements as possible (1 hr max.). Check all average values.

Form B-2 Test Plan Checklist (Cont'd)

Test Method		Activity
The Test	Alternative Test	
X	X	If all equipment functions correctly, prepare for the performance test. Coordinate all efforts through the Operators and the designated parties.
X	X	If a separate test of cooling-water flow is to be conducted simultaneously, coordinate with all testing parties.
X	X	Consider any special cycle isolation necessary to conduct concurrent tests.
X	X	Verify that cycle isolation is complete as required in the test plan.
X	X	Follow the test schedule and begin testing.
X	X	Make any schedule changes necessary to meet the scope and objectives of the test. Keep a test log to document any deviations from the test plan or the original testing schedule.
X	X	Review the data logs and reports to ensure that all instruments functioned properly throughout the test. Direct additional test runs if necessary.
X	X	Inform the Operators when the performance test is complete; they can return the cycle isolation to its normal operating mode.
X	X	Perform the necessary calculations and prepare a summary of the results for the designated parties.
X	X	Make copies of the data logs and reports for the designated parties.
X	X	Direct the technicians to remove all temporary test instrumentation, extension wire, and cable.

NONMANDATORY APPENDIX C AUTOMATIC DATA ACQUISITION

C-1 FUNCTIONS OF THE DATA ACQUISITION SYSTEM

This Appendix is presented as a guide for the implementation of an automatic data acquisition system (DAS). The DAS can

- (a) enhance data collection and analysis
- (b) allow for simultaneous reading and recording of all data points
- (c) provide data collection frequency exceeding that described in Section 3
- (d) provide data collection time measurements and synchronization as described in Section 3
- (e) provide data accuracy exceeding that described in subsection 4-3

C-2 ADDITIONAL FUNCTIONS OF THE DAS

A portable, computer-based DAS together with state-of-the-art sensor technology and analog-to-digital converter reliability can accomplish the objectives in subsection C-1. This type of DAS can also provide the following:

- (a) portability and ease of configuration
- (b) flexible network that can analyze sensor and acquisition faults
- (c) flags and alarms for out-of-range values
- (d) graphics for data trending and results presentation
- (e) mass data storage and ease of data retrieval
- (f) ease of calculation development and data export for third-party thermodynamic model analysis

C-3 ADVANTAGES OF THE DAS OVER MANUAL DATA COLLECTION

The DAS can provide certain enhancements that manual data collection cannot offer, such as

- (a) real-time data at very high sampling frequency
- (b) reduction in manual data collection personnel
- (c) reduction in data-recording errors
- (d) quick test-condition and results validation that leads to prevention of retest and associated costs (ASME PTC 19.22 [1] addresses this subject in detail)

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NONMANDATORY APPENDIX D PERFORMANCE MONITORING

D-1 INTRODUCTION

While this Code is written for the purpose of acceptance testing, this Nonmandatory Appendix addresses techniques that permit trending and condenser-performance evaluations during operation. Satisfactory performance monitoring can be achieved without the stringent instrument accuracy required for acceptance testing. That lack of a required absolute numerical level of test results is what distinguishes the focus, setup, and data-collection needs of a monitoring test plan from those of an acceptance test plan. Relative measurements and repeatability are critical. If the data prove to be repeatable during the same operating conditions, correction factors to absolute performance levels can always be developed from an analysis of those data sets.

This Appendix describes the considerations of condenser performance-monitoring tests.

D-2 STRUCTURE OF PERFORMANCE-MONITORING TESTS

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

A decision that significantly characterizes a condenser performance-monitoring program is whether to monitor periodically, continuously, or both. The major benefits of continuously monitoring condenser performance are the ability to ascertain when changes occur and what the related circumstances are, thus enabling the earliest operational or maintenance response; the ability to anticipate whether there will be more severe changes from the initial indications; and the continuous assessment of how the condenser influences power generation and costs. Nonetheless, a compromise may be considered that balances the one-time high capital costs and the ongoing maintenance cost of the continuous system's permanent instrumentation against the repetitive setup costs and data collection of the periodic test. Note also that more complex and reliable levels of performance monitoring will require increased quantities of instrumentation.

D-3 PARAMETERS TO MONITOR

The following parameters are recommended for monitoring and are listed in a general order of importance, though the actual list is always dictated by the overall program's objectives:

- (a) condenser terminal temperature difference
- (b) condenser back-pressure deviation from design
- (c) cooling-water flow or relative flow
- (d) temperature rise of cooling water
- (e) tube-bundle hydraulic pressure drop relative to discharge waterbox-to-piping pressure loss
- (f) air in-leakage
- (g) condensate subcooling

D-4 MONITORING MEASUREMENTS

The main body of this Code describes requirements for acceptance test measurements. These can be slightly relaxed and adapted for performance monitoring as long as the sensor in question is still sufficiently precise to reliably reflect the same relative test value as conditions change. See Table D-4-1.

Several notes are relevant to Table D-4-1. Most installed plant flow devices are not sufficiently accurate to serve as a primary flow-measurement device. This includes cooling-water flow devices, feedwater flow devices, and plant-stream venturis. A calibration of plant devices during an accurate test is necessary to monitor the flow properly. For example, prior to beginning performance monitoring, the pump TDH, outlet-waterbox pressure drop, or a pitot-static-type center reading should be correlated during a dye-dilution test. With regard to pressure and temperature instruments, refer to Section 4 in this Code. Some new instrumentation is likely required for a successful program. In addition, an automated quick purge of the pressure measurement lines before reading and some added temperature hardware at the outlet to reflect the temperature profile more adequately than a few shallow existing thermowells will significantly enhance the monitoring results.

D-5 CALCULATIONS

Refer to Section 5 for details on the computation of parameters for trending. All variables should be plotted with respect to time, inlet-water temperature, and

Table D-4-1 Performance Monitoring of Parameters

Measurement	Performance-Monitoring Methods
Cooling-water flow	Pump curves/TDH correlations, heat balance, calibrated flow instrument, outlet-waterbox differential pressure
Outlet cooling-water temperature	Use available instrumentation, and could be correlated with one-time test traverse or partial temperature rake
Tube cleanliness	Differential waterbox and outlet-waterbox pressures, expected back pressure, outlet temperature profile, terminal temperature difference
Condenser pressure	Existing locations near bundle; calibration of sensors required
Steam or condensate temperature	Existing locations; calibration check required
Air in-leakage	Same as Code or continuous meter type

GENERAL NOTE: To follow the example, all parameters that are in U.S. Customary units must be converted to SI units.

generation. Data should be normalized with respect to design heat-transfer coefficient, fouling, cooling-water flow, or air in-leakage. The ratio of the bundle versus the outlet-waterbox pressure drop should be plotted to aid in diagnosis of fouling increases. Significant conditions such as tube cleaning should be benchmarked. Commercially available online performance software may be considered to reduce calculation effort.

Data validity can be ensured by examining the statistical data variation and the degree of the compliance with respect to inlet temperature, station generation, or cooling-water flow. The data should be precise, consistent, and dependable. Suitable approximations can be made depending on the experience of the personnel and program goals.

NONMANDATORY APPENDIX E EXAMPLE CALCULATIONS

This example illustrates a thermal performance test of a steam surface condenser. It is based on a test of a single-pass condenser that provides heat rejection and condensation of the turbine exhaust steam from an electric-power-generating unit. Table E-1 provides the design-reference data for the condenser. Table E-2 summarizes the data collected during the test. Table E-3 summarizes the water and steam properties, determined using the ASME Steam Tables [5], for the design and test conditions. Table E-4 summarizes the data and calculations for the cleanliness factor determination, conducted in parallel with the test.

The example calculations follow the calculation procedures of Section 5.

E-1 BASIC HEAT-TRANSFER RELATIONS

E-1.1 Condenser Heat Load

The condenser heat load at the test conditions is computed as follows:

$$\begin{aligned} Q^+ &= w^+ c_p^+ (T_2^+ - T_1^+) \\ &= 678.8 \text{ MW} \left(2316 \frac{\text{MMBtu}}{\text{hr}} \right) \end{aligned}$$

NOTE: MW = megawatt

E-1.2 Overall Heat-Transfer Coefficient

The overall heat-transfer coefficient at the test conditions is computed as follows:

$$\begin{aligned} U^+ &= \frac{Q^+}{A_s LMTD^+} \\ &= 3203 \frac{\text{W}}{\text{m}^2 \cdot \text{C}} \left(564.2 \frac{\text{Btu}}{\text{hr} \cdot \text{ft}^2 \cdot \text{F}} \right) \end{aligned}$$

where

$$\begin{aligned} LMTD^+ &= \frac{(T_2^+ - T_1^+)}{\ln \left(\frac{T_s^+ - T_1^+}{T_s^+ - T_2^+} \right)} \\ &= 9.52^\circ\text{C} (17.1^\circ\text{F}) \end{aligned}$$

and the steam temperature is taken from the ASME Steam Tables [5].

NOTE: For the equations in this Appendix, all parameters that are in U.S. Customary units must be converted to SI units.

E-1.3 Tube-Wall Resistance

The tube-wall resistance is computed as follows:

$$\begin{aligned} R_m^+ &= \frac{D_o}{2k_m} \times \ln \left(\frac{D_o}{D_i} \right) \\ &= 2.933 \times 10^{-5} \frac{\text{m}^2 \cdot \text{C}}{\text{W}} \left(1.666 \times 10^{-4} \frac{\text{hr} \cdot \text{ft}^2 \cdot \text{F}}{\text{Btu}} \right) \end{aligned}$$

E-1.4 Tubeside Resistance

The calculation for the tubeside heat-transfer coefficient is taken from Rabas and Cane [6].

$$\begin{aligned} R^+ &= \left[0.0158 \frac{k^+}{D_i} (Re^+)^{0.835} (Pr^+)^{0.462} \right]^{-1} \\ &= 1.020 \times 10^{-4} \frac{\text{m}^2 \cdot \text{C}}{\text{W}} \left(5.792 \times 10^{-4} \frac{\text{hr} \cdot \text{ft}^2 \cdot \text{F}}{\text{Btu}} \right) \end{aligned}$$

where

$$\begin{aligned} Pr^+ &= \frac{c_p^+ \mu^+}{k^+} \\ &= 5.655 \end{aligned}$$

$$\begin{aligned} Re^+ &= \frac{4w^+ n^+}{\pi N D_i \mu^+} \\ &= 54\,253 \end{aligned}$$

E-1.5 Fouling Resistance

The average fouling resistance is calculated in accordance with the methodology presented in para. A-9.1, as follows:

$$\begin{aligned} R_f^+ &= \frac{1}{N} \sum_{i=1}^N R_{f,i}^+ \\ &= 4.118 \times 10^{-5} \frac{\text{m}^2 \cdot \text{C}}{\text{W}} \left(2.339 \times 10^{-4} \frac{\text{hr} \cdot \text{ft}^2 \cdot \text{F}}{\text{Btu}} \right) \end{aligned}$$

where

$$R_{f,i}^+ = \frac{A_o}{nw^+ c_p^+} \left[\frac{1}{\ln \left(\frac{T_s^+ - T_{1,f}^+}{T_s^+ - T_{2,f}^+} \right)} - \frac{1}{\ln \left(\frac{T_s^+ - T_{1,c}^+}{T_s^+ - T_{2,c}^+} \right)} \right]$$

Table E-1 Condenser Design Data

Condenser Description	
Type	Single pressure
Number of passes	1
Number of tubes	26,550
Tube material	90/10 Cu-Ni
Thermal conductivity, k , Btu/hr-ft ² -°F	26
Tube O.D., in.	0.875
Tube gauge, BWG	18
Tube wall, in.	0.049
Effective length, ft	39.375
Outside tube surface area, ft ²	239,476
Cooling-water flow area, ft ²	87.42
Design Conditions	
Inlet cooling-water temperature, °F	65
Outlet cooling-water temperature, °F	80.6
Cooling-water flow, gpm	280,000
Cooling-water flow, lb/hr	1.3989E + 08
Cleanliness factor, %	85
Condenser pressure, in. HgA	1.50
Condenser pressure, psia	0.74
Heat load, Btu/hr	2.1760E + 09
Tubeside pressure drop, ft H ₂ O	14.5
Condensing flow, lb/hr	2,222,185

Table E-2 Test Data

Test Measurement	Number of Measurement Points	Average Value	Number of Readings	Standard Deviation	Standard Deviation of the Mean
Inlet cooling-water temperature, °F	2	74.89	120	0.15	0.0194
Outlet cooling-water temperature, °F	8	90.7	480	0.45	0.0205
Cooling-water flow, gpm	1	294,410	12	2,115 [Note (1)]	610.54
Condenser pressure, psia	12	0.982	720	0.05	0.0019
Condensing flow, lb/hr	1	2,408,314	5	18,953	8,476.0
Tubeside pressure drop, ft H ₂ O	1	15.7	12	0.35	0.1010

NOTE:

(1) The average water flow rate was based on one pitot tube transverse. The standard deviation was based on 12 pitot tube readings of the pipe centerpoint; these are the number of estimates.

Table E-3 Steam and Water Properties

	Design	Test
Condenser Steam Properties		
Condenser pressure, in. HgA	1.5	2.0
Condenser saturation temperature, °F	91.72	101.14
Density, lb/ft ³ [Note 1]	0.0022	0.0029
Circulating-Water Fluid Properties		
Bulk average cooling-water temperature, °F	72.8	82.8
Specific heat, Btu/lb·°F	0.9986	0.9981
Thermal conductivity, Btu/hr·ft ² ·°F	0.03489	0.3539
Viscosity, lb/ft·hr	2.275	2.005
Density, lb/ft ³	62.28	62.19

NOTE:

- (1) Steam density is based on saturation conditions. This is generally of sufficient accuracy for use in the adjusted steam-side resistance calculation. If greater accuracy is required, the moisture content of the steam can be determined from the steam enthalpy, where the steam enthalpy is determined from the calculated heat duty and the measured condensing-steam flow rate.

Table E-4 Fouling-Resistance Determination Test

Tube Set	T_1 , °F	T_2 , °F	T_p , °F	T_c , °F	R_p , hr · ft ² · °F/Btu
1	74.9	101.14	91.9	93.1	0.000183
2	74.9	101.14	92.3	93.7	0.000205
3	74.9	101.14	92.3	93.8	0.000218
4	74.9	101.14	91.9	93.4	0.000226
5	74.9	101.14	91.6	93.2	0.000247
6	74.9	101.14	91.4	93.1	0.000266
7	74.9	101.14	92.6	93.9	0.000186
8	74.9	101.14	92.8	94.0	0.000169
9	74.9	101.14	92.3	93.9	0.000232
10	74.9	101.14	92.0	93.8	0.000266
11	74.9	101.14	91.5	93.2	0.000264
12	74.9	101.14	91.4	93.0	0.000252
13	74.9	101.14	91.5	93.2	0.000264
14	74.9	101.14	91.3	93.1	0.000283
					Avg. = 0.000233

E-1.6 Shellside Resistance

The shellside resistance at the test conditions is determined using the following equation:

$$R_s^+ = \frac{1}{U^+} - R_m^+ - R_i^+ \left(\frac{D_o}{D_i} \right) - R_f^+ \\ = 1.268 \times 10^{-4} \frac{\text{m}^2 \cdot \text{C}}{\text{W}} \left(7.198 \times 10^{-4} \frac{\text{hr} \cdot \text{ft}^2 \cdot \text{F}}{\text{Btu}} \right)$$

E-2 CONDENSER-PRESSURE DEVIATION CALCULATIONS

E-2.1 Condenser Heat Load

The condenser heat load at the test conditions is computed as follows:

$$Q^* = w^* c_p^* (T_2^* - T_1^*) \\ = 638.7 \text{ MW} \left(2 \ 179 \frac{\text{MMBtu}}{\text{hr}} \right)$$

E-2.2 Overall Heat-Transfer Coefficient

The overall heat-transfer coefficient at the test conditions is computed as follows:

$$U^* = \frac{Q^*}{A_o LMTD^*} \\ = 2904 \frac{\text{W}}{\text{m}^2 \cdot \text{C}} \left(511.4 \frac{\text{Btu}}{\text{hr} \cdot \text{ft}^2 \cdot \text{F}} \right)$$

where

$$LMTD^* = \frac{(T_2^* - T_1^*)}{\ln \left(\frac{T_s^* - T_1^*}{T_s^* - T_2^*} \right)} \\ = 9.89^\circ\text{C} \ (17.8^\circ\text{F})$$

and the steam temperature is taken from the ASME Steam Tables [5].

E-2.3 Tube-Wall Resistance

The tubewall Resistance is a constant that is dependent only on the tube-wall thickness and material. Therefore,

$$R_m^\circ = R_m^* = R_m^+$$

E-2.4 Tubeside Resistance

The tubeside heat-transfer coefficient is calculated at the design conditions as follows:

$$R_i^\circ = R_i^* = \left[0.0158 \frac{k^*}{D_i} (Re^*)^{0.835} (Pr^*)^{0.462} \right]^{-1} \\ = 1.122 \times 10^{-4} \frac{\text{m}^2 \cdot \text{C}}{\text{W}} \left(6.371 \times 10^{-4} \frac{\text{hr} \cdot \text{ft}^2 \cdot \text{F}}{\text{Btu}} \right)$$

where

$$Pr^* = \frac{c_p^* \mu^*}{k^*} \\ = 6.511$$

$$Re^* = \frac{4w^* n^*}{\pi N D_i \mu^*} \\ = 45 \ 542$$

E-2.5 Fouling Resistance

The design fouling factor is determined from the design cleanliness factor as follows:

$$R_f^\circ = R_f^* = \frac{1 - c_f^*}{U^*} \\ = 5.166 \times 10^{-5} \frac{\text{m}^2 \cdot \text{C}}{\text{W}} \left(2.933 \times 10^{-4} \frac{\text{hr} \cdot \text{ft}^2 \cdot \text{F}}{\text{Btu}} \right)$$

E-2.6 Shellside Resistance

The shellside resistance adjusted to the design conditions is determined as follows:

Step 1: Calculate the condensate film temperature at design condition as follows:

$$T_f^* = T_s^* - 0.2 LMTD^* \\ = 31.4^\circ\text{C} \ (88.2^\circ\text{F})$$

Step 2: Calculate the condensate film temperature at test condition as follows:

$$T_f^+ = T_s^+ - 0.2 LMTD^+ \\ = 36.7^\circ\text{C} \ (97.7^\circ\text{F})$$

Step 3: Solve for the adjusted shellside resistance, where μ , k , and ρ are physical properties at the design and test conditions taken from Nonmandatory Appendix I:

$$R_s^\circ = R_s^+ \left(\frac{w_s^+}{w_s^*} \right)^{1/3} \left(\frac{\mu_1^+}{\mu_1^*} \right)^{1/3} \left(\frac{k_1^+}{k_1^*} \right) \left(\frac{\rho_1^+}{\rho_1^*} \right)^{2/3} \\ = 1.243 \times 10^{-4} \frac{\text{m}^2 \cdot \text{C}}{\text{W}} \left(7.060 \times 10^{-4} \frac{\text{hr} \cdot \text{ft}^2 \cdot \text{F}}{\text{Btu}} \right)$$

E-2.7 Overall Heat-Transfer Coefficient

The overall heat-transfer coefficient, adjusted to the design conditions, is calculated as follows:

$$U^o = \frac{1}{R_m^o + R_t^o \left(\frac{d_o}{d_i} \right) + R_f^o + R_s^o}$$

$$= 3\,015 \frac{\text{W}}{\text{m}^2 \cdot \text{C}} \left(531.0 \frac{\text{Btu}}{\text{hr} \cdot \text{ft}^2 \cdot \text{F}} \right)$$

E-2.8 Effectiveness – NTU Method

The test steam condenser steam pressure, adjusted to the design-reference conditions, is determined as follows:

$$NTU^o = \frac{U^o A_o}{c_p^* w^*}$$

$$= 0.91$$

$$T_s^o = \frac{T_2^* - T_1^* e^{-NTU^o}}{1 - e^{-NTU^o}}$$

$$= 33.02^\circ\text{C} (90.11^\circ\text{F})$$

And the steam pressure adjusted to design-reference conditions is found in the ASME Steam Tables [5]:

$$P_s^o = f(T_s^o)$$

$$= 4.988 \text{ kPa} (0.72 \text{ psia})$$

E-2.9 Evaluation of Results

The difference between the test-adjusted and design-reference steam pressures are evaluated as follows:

$$\Delta P_s = P_s^* - P_s^o$$

$$= 0.114 \text{ kPa} (0.017 \text{ psid})$$

Therefore, the condenser is operating slightly better than required by the design criteria.

E-3 TUBESIDE PRESSURE-DROP DEVIATION CALCULATIONS

The test-measured tubeside pressure drop is adjusted for differences between the test and design-reference water flow rates as follows:

$$\Delta P_t^o = \Delta P_t^+ \left(\frac{w^*}{w^o} \right)^{1.8}$$

$$= 4.38 \text{ m} (14.4 \text{ ft})$$

Therefore, the condenser tubeside pressure drop is less than that specified by the design criteria.

E-4 UNCERTAINTY ANALYSIS

E-4.1 Uncertainty in Test-Adjusted Steam Pressure

E-4.1.1 Sensitivity Coefficients. The sensitivity coefficients of test-adjusted steam pressure with respect to the measured variables are computed by substituting the design and test values into the equations provided in the following sections. Each sensitivity coefficient is derived using the chain rule. However, the sensitivity coefficients may be more easily obtained numerically using small perturbations of the measured/design variables. This methodology is equivalent to using the chain rule when linear sensitivity coefficients exist.

(a) Sensitivity coefficient for steam flow rate

$$\theta_{w_s^*} = F_1 F_2 \left(\frac{1}{3} \frac{R_s^o}{W s^+} \right)$$

where

$$F_1 = 0.00169 e^{0.02736 T_s^*}$$

$$F_2 = \frac{(T_2^* - T_1^*) NTU^o U^o e^{NTU^*}}{(1 - e^{NTU^*})^2}$$

(b) Sensitivity coefficient for circulating-water flow rate

$$\theta_{w^+} = F_1 F_2 \frac{R_s^o}{R_s^+} \left[\frac{-\frac{1}{U^+} + 0.835 R_t^+ \left(\frac{d_o}{d_i} \right) + R_f^+}{w^+} \right]$$

(c) Sensitivity coefficient for inlet-water temperature

$$\theta_{T_1^+} = F_1 F_2 \frac{R_s^o}{R_s^+} \left[\frac{A_o}{w^+ c_p^+ \ln \left(\frac{T_s^+ - T_1^+}{T_s^+ - T_2^+} \right)^2 (T_s^+ - T_1^+)} \right]$$

(d) Sensitivity coefficient for outlet-water temperature

$$\theta_{T_2^+} = F_1 F_2 \frac{R_s^o}{R_s^+} \left[\frac{-A_o}{w^+ c_p^+ \ln \left(\frac{T_s^+ - T_1^+}{T_s^+ - T_2^+} \right)^2 (T_s^+ - T_2^+)} \right]$$

(e) Sensitivity coefficient for cleanliness factor fouled tube inlet temperature

Table E-4.1.2-1 Sensitivity Coefficients for Test-Adjusted Steam Pressure and Standard Uncertainties

Measured Parameter	Sensitivity Coefficient	Standard Systematic Uncertainty	Standard Random Uncertainty
Steam flow, Ws^+	1.681E-8 psia-hr/lb	30,000 lb/hr	8,476 lb/hr
Cold-water flow, w^+	-1.141E-9 psia-hr/lb	2,500,000 lb/hr	305,555 lb/hr
Inlet cooling-water temperature, T_1^+	0.012 psia/°F	0.2°F	0.0194°F
Outlet cooling-water temperature, T_2^+	-0.0031 psia/°F	0.2°F	0.021°F
Condenser pressure, P_s^+	0.661 psia/psia	0.025 psia	0.0019 psia
Cleanliness factor fouled tubes inlet temperature, T_{f1}^+	0.0096 psia/°F	0.2°F	0.021°F
Cleanliness factor fouled tubes outlet temperature, T_{f2}^+	0.027 psia/°F	0.2°F	0.09°F
Cleanliness factor clean tubes inlet temperature, T_{c1}^+	0.00695 psia/°F	0.2°F	0.021°F
Cleanliness factor clean tubes outlet temperature, T_{c2}^+	-0.024 psia/°F	0.2°F	0.09°F

$$\theta_{T_{1,f}} = F_1 F_2 \frac{R_s^o}{R_s^+} \left[\frac{-A_o}{nw^+ c_p^+ \ln \left(\frac{T_s^+ - T_{1,f}^+}{T_s^+ - T_{2,f}^+} \right)^2 (T_s^+ - T_{1,f}^+)} \right]$$

(f) Sensitivity coefficient for cleanliness factor fouled tube outlet temperature

$$\theta_{T_{2,f}} = F_1 F_2 \frac{R_s^o}{R_s^+} \left[\frac{-A_o}{nw^+ c_p^+ \ln \left(\frac{T_s^+ - T_{1,f}^+}{T_s^+ - T_{2,f}^+} \right)^2 (T_s^+ - T_{2,f}^+)} \right]$$

(g) Sensitivity coefficient for cleanliness factor clean tube inlet temperature

$$\theta_{T_{1,c}} = F_1 F_2 \frac{R_s^o}{R_s^+} \left[\frac{A_o}{nw^+ c_p^+ \ln \left(\frac{T_s^+ - T_{1,c}^+}{T_s^+ - T_{2,c}^+} \right)^2 (T_s^+ - T_{1,c}^+)} \right]$$

(h) Sensitivity coefficient for cleanliness factor clean tube outlet temperature

$$\theta_{T_{2,c}} = F_1 F_2 \frac{R_s^o}{R_s^+} \left[\frac{-A_o}{nw^+ c_p^+ \ln \left(\frac{T_s^+ - T_{1,c}^+}{T_s^+ - T_{2,c}^+} \right)^2 (T_s^+ - T_{2,c}^+)} \right]$$

(i) Sensitivity coefficient for steam pressure

$$\theta_{T_s} = \frac{1}{F_a} \left\{ -\theta_{T_1^+} \left[1 - \frac{T_s^+ - T_1^+}{T_s^+ - T_2^+} \right] - \left[\frac{\theta_{T_{1,f}}}{n} \left(1 - \frac{T_s^+ - T_{1,f}}{T_s^+ - T_{2,f}} \right) + \frac{\theta_{T_{1,c}}}{n} \left(1 - \frac{T_s^+ - T_{1,c}}{T_s^+ - T_{2,c}} \right) \right] \right\}$$

where

$$F_a = \frac{1}{0.00169e^{0.02736T_s^+}}$$

E-4.1.2 Standard Systematic and Standard Random Uncertainties.

The standard systematic and standard random uncertainties for each of the measured parameters were determined in accordance with the methodology presented in ASME PTC 19.1 [1]. The values in Table E-4.1.2-1 are provided for example purposes only. Although these values are typical for a test conducted in accordance with this Code, actual values shall be determined for a specific test and shall depend on the condenser design, the instrumentation used, and the test operating conditions. For this example, the standard systematic and standard random uncertainties associated with the test results are described in para. E-4.1.3.

E-4.1.3 Uncertainty in Steam Pressure.

An estimate of the uncertainty in the test steam pressure, adjusted to the design-reference conditions, is calculated below. The standard systematic uncertainties, standard random uncertainties, and sensitivity coefficients are taken directly from Table E-4.1.2-1.

(a) Standard systematic uncertainty

$$\begin{aligned} b_{P_s^+}^2 &= (\theta_{Ws^+} b_{Ws^+})^2 + (\theta_{w^+} b_{w^+})^2 + (\theta_{P_s^+} b_{P_s^+})^2 \\ &\quad + (\theta_{T_1^+} b_{T_1^+})^2 + (\theta_{T_2^+} b_{T_2^+})^2 + (\theta_{T_{1,f}} b_{T_{1,f}})^2 \\ &\quad + (\theta_{T_1^+} b_{T_1^+})^2 + (\theta_{T_2^+} b_{T_2^+})^2 + (\theta_{T_{1,f}} b_{T_{1,f}})^2 \\ &\quad + (\theta_{T_{2,f}} b_{T_{2,f}})^2 + (\theta_{T_{1,c}} b_{T_{1,c}})^2 + (\theta_{T_{2,c}} b_{T_{2,c}})^2 \\ &= 0.00038 \text{ psia}^2 \end{aligned}$$

(b) Standard random uncertainty

$$\begin{aligned} S_{Ps}^{2*} &= (\theta_{Ws^+} S_{Ws^+})^2 + (\theta_{w^+} S_{w^+})^2 + (\theta_{Ps^+} S_{Ps^+})^2 \\ &+ (\theta_{T_1^+} S_{T_1^+})^2 + (\theta_{T_2^+} S_{T_2^+})^2 + (\theta_{T_{1,f}} S_{T_{1,f}})^2 \\ &+ (\theta_{T_1^+} S_{T_1^+})^2 + (\theta_{T_2^+} S_{T_2^+})^2 + (\theta_{T_{1,f}} S_{T_{1,f}})^2 \\ &+ (\theta_{T_{2,f}} S_{T_{2,f}})^2 + (\theta_{T_{1,c}} S_{T_{1,c}})^2 + (\theta_{T_{1,c}} S_{T_{1,c}})^2 \\ &= 1.287E-5 \text{ psia}^2 \end{aligned}$$

(c) Standard uncertainty

$$\begin{aligned} Un_{Ps} &= \sqrt{b_{Ps}^2 + S_{Ps}^2} \\ &= 0.020 \text{ psia} \end{aligned}$$

(d) Uncertainty at 95% confidence

$$\begin{aligned} U_{Ps} &= 2Un_{Ps} \\ &= 0.040 \text{ psia} \end{aligned}$$

E-4.2 Uncertainty in Tubeside Pressure Drop

An estimate of the uncertainty in the test tubeside pressure drop, adjusted to the design-reference conditions, is calculated as follows:

(a) Sensitivity coefficient for adjusted tubeside pressure drop

$$\begin{aligned} \theta_{\Delta P_w^+} &= \frac{\Delta P_w^o}{\Delta P_w^+} \\ &= 0.90446 \end{aligned}$$

(b) Sensitivity coefficient for circulating-water flow rate

$$\begin{aligned} \theta_{\Delta P_w^+} &= \frac{1.8 \Delta P_w^o}{w^+} \\ &= 1.7403E-07 \frac{\text{ft H}_2\text{O} \cdot \text{hr}}{\text{lb}} \end{aligned}$$

The standard uncertainty in the tubeside pressure drop is calculated in para. E-4.2.1. The systematic standard uncertainty associated with the tubeside pressure drop is taken as 1.5% of the mean of the readings.

E-4.2.1 Standard Systematic Uncertainty

$$\begin{aligned} b_{\Delta P_w^+} &= \sqrt{(\theta_{\Delta P_w^+} b_{\Delta P_w^+})^2 + (\theta_{\Delta P_w^+} b_{\Delta P_w^+})^2} \\ &= 0.484 \text{ ft H}_2\text{O} \end{aligned}$$

E-4.2.2 Standard Random Uncertainty

$$\begin{aligned} S_{\Delta P_w^+} &= \sqrt{(\theta_{\Delta P_w^+} S_{\Delta P_w^+})^2 + (\theta_{\Delta P_w^+} S_{\Delta P_w^+})^2} \\ &= 0.106 \text{ ft H}_2\text{O} \end{aligned}$$

E-4.2.3 Standard Uncertainty

$$\begin{aligned} Un_{\Delta P_w^+} &= \sqrt{b_{\Delta P_w^+}^2 + S_{\Delta P_w^+}^2} \\ &= 0.485 \text{ ft H}_2\text{O} \end{aligned}$$

According to Coleman and Steele [7], a Student's t value equal to 2 is an adequate approximation for $N \geq 10$ measurements. Therefore, the total uncertainty in the tubeside pressure drop at 95% confidence is

$$\begin{aligned} U_{\Delta P_w^+} &= 2Un_{\Delta P_w^+} \\ &= 0.991 \text{ ft H}_2\text{O} \end{aligned}$$

E-4.2.4 Uncertainty Results

The following presents uncertainty results using selected condenser measurement uncertainties. The uncertainties for the Code test and the alternative test are compared in Table E-4.2.4-1.

To calculate the uncertainty in steam pressure at 95% confidence using the sensitivity coefficients presented in Table E-4.2.4-1, the following equation is used:

$$\begin{aligned} Un_{Ps}^2 &= (\theta_{Ws^+} Un_{Ws^+})^2 + (\theta_{w^+} Un_{w^+})^2 + (\theta_{Ps^+} Un_{Ps^+})^2 \\ &+ (\theta_{T_1^+} Un_{T_1^+})^2 + (\theta_{T_2^+} Un_{T_2^+})^2 + (\theta_{T_{1,f}} Un_{T_{1,f}})^2 \\ &+ (\theta_{T_{2,f}} Un_{T_{2,f}})^2 + (\theta_{T_{1,c}} Un_{T_{1,c}})^2 + (\theta_{T_{1,c}} Un_{T_{1,c}})^2 \end{aligned}$$

Assuming $N \geq 10$ measurements and independent measured variables, the total uncertainty in the test-adjusted steam pressure at 95% confidence may be approximated as follows:

$$U_{Ps} = 2Un_{Ps}$$

The same methodology and assumptions are used to calculate the uncertainty associated with test-adjusted tubeside pressure drop and dissolved oxygen. The results for the expected uncertainty of both tests are shown in Table E-4.2.4-1.

Table E-4.2.4-1 Results for the Expected Uncertainty

Instrument Measurement	Test Uncertainty [Note (1)]	Alternative Test Uncertainty
Condenser pressure	0.1 in. Hg [Note (2)]	0.05 in. Hg [Note (2)]
Inlet-water temperature	0.2°F [Note (2)]	0.1°F
Outlet-water temperature	0.2°F [Note (2)]	0.1°F [Note (2)]
Cleanliness factor fouled tubes inlet temperature	0.2°F	0.1°F
Cleanliness factor fouled tubes outlet temperature	0.2°F	0.1°F [Note (2)]
Cleanliness factor clean tubes inlet temperature	0.2°F	0.1°F
Cleanliness factor clean tubes outlet temperature	0.2°F	0.1°F [Note (2)]
Cooling-water flow	3% [Note (2)]	2% [Note (2)]
Condensing flow	3%	2%
Tubeside pressure loss	2%	1% [Note (2)]
	Test Uncertainty at 95% Confidence	Alternative Test Uncertainty at 95% Confidence
Test-adjusted steam pressure	0.133 in. Hg	0.066 in. Hg
Test-adjusted tubeside pressure drop	1.635 ft H ₂ O	1.061 ft H ₂ O
Subcooling	0.2°F	0.2°F
Dissolved oxygen	2 ppb	2 ppb

GENERAL NOTE: The values shown are examples only and should not be considered typical or expected values in a real test.

NOTES:

- (1) For the test, the uncertainty associated with the assumption of tube cleanliness is characterized by higher uncertainty of the fouled and clean tube inlet and outlet temperature.
- (2) These values pertain to the previous sample calculations but fall beyond the prescribed uncertainty values detailed in Table E-4.1.2-1.

NONMANDATORY APPENDIX F

AIR BINDING

F-1 INTRODUCTION

Air binding is a term used to describe the insulating effect of air on condenser tubes when the space between the tubes is filled with air. Air-bound regions of a tube bundle are those that have a high air mole fraction.

F-2 EFFECTS OF AIR BINDING

In an ideal situation, the condensing pressure achievable in a steam surface condenser is determined by the exiting cooling-water temperature. However, the presence of a noncondensable gas creates an additional thermal resistance to the condensation heat transfer, reducing the heat-transfer rate.

There is always some small residual amount of air in-leakage into the turbine or condenser system through penetrations or due to noncondensable gases produced by the action of the chemicals used to treat the feedwater. This air ingress cannot be avoided, and the design value used for the condenser tubeside heat-transfer coefficient reflects this added resistance.

However, if the air mole fraction present in the tube bundle exceeds the design value for whatever reason (high air in-leakage, diminished capacity of the air-removal system, etc.), the condenser heat exchange decreases, thus raising the condensing pressure and the dissolved-oxygen concentration in the condensate.

F-3 CAUSES OF AIR BINDING

The possible causes of air binding are

- (a) air in-leakage in excess of the air-removal system's capacity
- (b) diminished capacity of the air-removal equipment
- (c) insufficient space around the tube bundle to permit steam to enter at all points around the periphery of the bundle and to achieve full steam penetration
- (d) a high hotwell level preventing steam from entering the bottom portion of the bundle
- (e) ineffective design of the air-removal zone
- (f) off-design operating conditions such as slow load operation and start-ups (e.g., cycling)
- (g) steam bypassing to the air-removal section because of design or construction deficiencies or because of component failures (e.g., baffle corrosion)

F-4 METHODS FOR DETECTING AIR BINDING

F-4.1 Identifying the Presence of Air Binding

The methods described in paras. F-4.1.1 through F-4.1.3 can be used to determine if air binding is occurring.

F-4.1.1 Increasing the Venting Equipment Capacity. This can be done by adding a redundant vacuum element or by turning on the hogging unit (if available). If the operating pressure in the condenser decreases significantly while the other factors (load, cooling-water flow, and temperature) remain constant, then the condenser is air bound.

F-4.1.2 Load Versus Back-Pressure Deviation. The condenser performance curves show the expected condenser pressure versus heat load for a fixed cooling-water flow entering the condenser at a given inlet temperature.

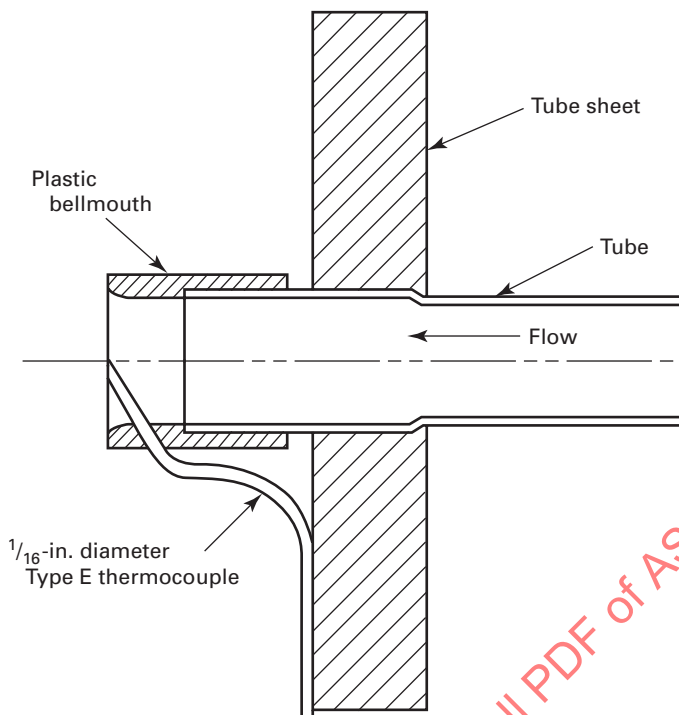
If air binding occurs, the back-pressure deviation, calculated as the difference between the measured absolute pressure of the condenser at given conditions and the expected vacuum pressure at those conditions according to the performance curves, will increase as long as the load is being reduced.

F-4.1.3 Outlet-Temperature Stratification. Because air binding prevents the entrance of steam into the regions of the tube bundle where air binding is occurring, the cooling-water temperature rise in the portion of the tubes that extends through the air-bound region is reduced significantly. Therefore, an accurate measure of tube temperature rise can be used to identify clearly the presence of air binding and to determine the location and extent of the air-bound region. This method is explained in detail in para. F-4.2.

F-4.2 Air-Binding Test

The principal objective of an air-binding test is to identify the presence of and quantify the extent of air binding at full load. Another objective may include identifying and quantifying the extent of air binding and deaeration performance during one and two vacuum pump operations, or one and two air-ejector operations at various loads and under various controlled air in-leakage rates.

Fig. F-4.2.1-1 Tube Outlet Temperature Measurement



F-4.2.1 Description of Test Method, Equipment, and Instrumentation. The application of 1.6 mm ($1/16$ in.) diameter Type E thermocouples, located in a uniform pattern, insulated and encased in flexible shields, and installed as the hot junction in the discharge flow path of the selected tubes, will identify air-bound regions. The discharge path thermocouples should be installed with the aid of nylon or plastic fittings (see Fig. F-4.2.1-1). The thermocouples should be attached to the tube sheet with tube collars and "p" clips, epoxy, or both, and routed to a connection in the waterbox. Several alternate methods have been used to install the thermocouples.

The thermocouples shall be specified to be accurate to $\pm 0.15^\circ\text{C}$ ($\pm 0.30^\circ\text{F}$). They shall be installed in a uniform pattern with at least one thermocouple per 100 tubes. The air-cooling zone shall be provided with a minimum of one thermocouple per 50 tubes. One thermocouple shall also be installed in the inlet waterbox of the same bundle. This can provide a reference junction to measure the temperature rise. Another thermocouple shall be installed in the inlet waterbox to measure absolute inlet-water temperature. Air binding that runs the full length of the bundle will result in these tube sections having virtually no temperature rise. Air binding is also often unevenly distributed along the length of the bundle and

then may result in a significantly less-than-expected temperature rise.

F-5 CORRECTING FOR AIR BINDING

As explained in subsection F-3, air binding occurs for several reasons. The solution, therefore, depends on the cause. When an air-binding problem is detected, the following diagnostic should be conducted:

(a) Check for air in-leakage. To determine if there is air in-leakage, see Nonmandatory Appendix G.

(1) If air in-leakage has been determined to be a problem, the leak(s) should be found and sealed or repaired.

(2) If air in-leakage has been determined not to be the problem, the venting equipment should be checked to ensure it is functioning properly. See Nonmandatory Appendix G.

(b) Determine whether the air-removal equipment is actually limiting the vacuum level. If that is the case, one of the solutions included in the flowchart in Nonmandatory Appendix G (see Fig. G-4-1) should be used to correct the problem.

(c) Determine whether it is necessary to rule out a problem of steam bypassing to the condenser air-removal section. This can be done by measuring the

temperature at the condenser vent connection. A temperature higher than or equal to the temperature of the condenser outlet cooling water is an indication of a high vapor load in the mixture. When this condition is allowed to persist, the performance of the venting equipment will be adversely affected sooner or later.

A steam-bypass problem can be a symptom of construction deficiencies, component failures (e.g., baffle corrosion), or even a design problem.

(d) If none of the reasons explained above are responsible for the air-binding problem, then the system should be examined for one of the operating or design problems listed in subsection F-3.

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