ASME PTC 39-2005

(Revision and Redesignation of ASME PTC 39.1-1980)

Steam Traps

Performance Test Codes

AN AMERICAN NATIONAL STANDARD

The American Society of Mechanical Engineers

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The American Society of Mechanical Engineers
Three Park Avenue • New York, NY 10016

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This Code will be revised when the Society approves the issuance of a new edition. There will be no addenda issued to ASME PTC 39-2005.

ASME issues written replies to inquiries as code cases and interpretations of technical aspects of this document. Code cases and interpretations are published on the ASME Web site under the Committee Pages at http://www.asme.org/codes/ as they are issued.

The American Society of Mechanical Engineers
Three Park Avenue, New York, NY 10016-5990

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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.

FOREWORD

The Performance Test Codes Supervisory Committee, at its June 1974 Administrative meeting, authorized the formation of a Code Technical Committee to explore the possibility of writing a test code on condensate removal devices. This committee was organized January 15, 1975. At its organizational meeting, the committee proposed the writing of two codes, PTC 39.1 on Condensate Removal Devices for Steam Systems and PTC 39.2 on Condensate Removal Devices for Air Systems. This proposal was approved by the Performance Test Codes Supervisory Committee.

The Code for Condensate Removal Devices for Steam Systems was approved by the Performance Test Codes Supervisory Committee on April 1, 1980. It was further approved as an American National Standard by the ANSI Board of Standard Review on July 3, 1980.

This committee has been operating as PTC 39 Steam Traps.

The original document was a compromise which had three sets of existing test equipment to be utilized. We therefore satisfied the consensus standard.

The current document is generic and can fit other test platforms too.

The original publication was submitted without an uncertainty analysis. Mr. David Fisher of Armstrong Machine Works offered a magnificent theoretical treatise which is in our Appendix I.

It is a privilege to acknowledge the efforts of those who are currently not on the committee:

Thomas Alesson, Datron Systems — Nicholson Division
Warren Brand, Yarway
Thomas W. Carr, Jr., Spirax Sarco Inc.
Robert Collins, Watson Daniel Co.
Walter T. Deacon, Armstrong Machine Works
Keith Foley, Celanese Canada, Inc.
Robert W. Henry, Salt River Project — Power Generation Systems
Milton Hilmer, Sarco
David Kalix, Yarway Corp.
William Mashburn, Virginia Polytechnic Institute and State University — Mechanical Engineering Department
Elmer S. Monroe, DuPont
James W. Murdock, Mechanical Engineering of Drexel University
Richard G. Obst, Spence Engineering Co., Inc./Nicholson Steam Trap
William H. Schilling, Schilling Associates Inc.
William F. Sisson, Armstrong Machine Works
Horst R. Thieme, Watson McDaniel Co.

We are aware that the preferred SI unit for time is seconds. However, the overwhelming customary unit in our industry is the capacity dimension of lb mass/hour. We have chosen to not include the rigorous usage but continue that which is common usage.

ASME PTC 39-2005 was adopted by the American National Standards Institute as an American National Standard on May 5, 2005.

PERFORMANCE TEST CODE COMMITTEE PTC 39 ON STEAM TRAPS

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

COMMITTEE OFFICERS

E. F. Gregg, *Chair*
M. A. Brookes, *Secretary*

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S. M. Bisgrove, Spence Engineering Co., Inc.
M. A. Brookes, The American Society of Mechanical Engineers
E. F. Gregg, Consulting Engineer
M. P. Hellman, Armstrong International Inc.
D. W. Fischer, *Alternate*, Armstrong International Inc.
W. E. Johnston, WEJ Energy Management Specialists, Inc.
S. J. Korellis, Dynegy Midwest Generation
A. A. Kornhauser, Virginia Tech

BOARD ON PERFORMANCE TEST CODES

CORRESPONDENCE WITH THE PTC 39 COMMITTEE

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

Secretary, PTC 39 Standards Committee
The American Society of Mechanical Engineers
Three Park Avenue
New York, NY 10016-5990

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

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

Interpretations. Upon request, the PTC 39 Committee will render an interpretation of any requirement of the Code. Interpretations can only be rendered in response to a written request sent to the Secretary of the PTC 39 Standards Committee.

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

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

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

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

Attending Committee Meetings. The PTC 39 Standards Committee regularly holds meetings, which are open to the public. Persons wishing to attend any meeting should contact the Secretary of the PTC 39 Standards Committee.

INTRODUCTION

This Code provides for the testing of steam traps in order to determine performance characteristics. It is based on the use of accurate instrumentation and the best analytical and measurement procedures currently available.

A study of the Code on General Instructions, PTC 1, is recommended as an introduction to essential procedures necessary for the proper use of this Code. The mandatory requirements contained therein are incorporated in this Code in Section 3.

The Code on Definitions and Values, PTC 2, defines certain technical terms and numerical constants, and their use is mandatory when applicable.

Reference is made to Performance Test Code Supplements on Instruments and Apparatus, PTC 19 series (abbreviated I&A), for general information and instructions on instrumentation. The specific directions of this Code, however, shall prevail for any instrument, procedure, or measurement which may differ from that given in another ASME publication.

This Code is recommended for use in conducting acceptance tests of steam traps. If so used, any deviations from Code procedure must be agreed upon in writing. In the absence of any written agreement, the code requirements shall be mandatory.

STEAM TRAPS

Section 1
Object and Scope

1-1 SCOPE

This Code covers steam traps which are devices used for removing condensate and noncondensibles from steam systems.

1-2 OBJECT

The purpose of this Code is to specify and define the practice of conducting tests of steam traps to determine:

(*a*) steam loss, under specified conditions. This test procedure does not account for convection and radiation losses. These can be determined separately.

(*b*) condensate discharge capacity, for specified conditions of saturated and subcooled condensate and back pressure.

(*c*) air and noncondensible gas removal capacity, under specified conditions.

1-3 UNCERTAINTY ANALYSIS

This Code includes the methods and examples to determine the uncertainty of the tests performed in accordance with it. This Committee prefers to define the test instrumentation and limit the allowable data fluctuations. This is equivalent to putting an upper limit on the allowable post-test uncertainty and ensures the validity of the test.

This Committee suggests that the post-test uncertainty should not exceed the following:

Quantity	Uncertainty
Condensate discharge rate less than 200 lbm/hr (91 kg/h)	10%
Condensate discharge rate 200 lbm/hr or greater (91 kg/h)	5%
Air discharge rate	10%
Steam loss rate greater than 20 lbm/hr (9.1 kg/h)	10%
Steam loss rate 20 lbm/hr (9.1 kg/h) down to 5 lbm/hr (2.3 kg/h)	15%
Steam loss rate 5 lbm/hr (2.3 kg/h) down to 1 lbm/hr (450 g/h)	25%

However, the steam loss calculations involve the differences of very large numbers and at low steam loss rates, the post-test uncertainty can become very large.

Section 2
Definitions and Descriptions of Terms

2-1 GENERAL

For terms and definitions not included in this Section, reference should be made to ASME PTC 2, Code on Definitions and Values.

2-2 STEAM TRAP

A device which permits the removal of condensate and air and other noncondensible gases, for steam systems at or below saturated steam temperature, and prevents or limits the discharge of live steam.

2-3 CAPACITY OF A STEAM TRAP

The amount of condensate per unit time which will be discharged continuously from the steam trap under specified conditions of pressure differential and inlet subcooling. Capacity is expressed in units of pounds mass per hour or kilograms per hour.

2-4 PRESSURE

Pressure is expressed in units of pounds force per square inch or pascals.

(*a*) Absolute pressure is the algebraic sum of the atmospheric pressure and gage pressure.

(*b*) Atmospheric pressure is the force per unit area exerted by the atmosphere. Standard atmospheric pressure is 760 mm of mercury at 0°C. This is equivalent to 101.325 kPa and 14.696 psia.

(*c*) Gage pressure is pressure measured with respect to the atmospheric pressure.

(*d*) Inlet pressure is the gage pressure measured at the steam trap inlet.

(*e*) Discharge pressure is the gage pressure measured at steam trap outlet.

(*f*) Differential pressure is the difference between the inlet pressure and the discharge pressure.

2-5 INLET SUBCOOLING

The difference between saturated steam temperature corresponding to the inlet pressure and the temperature of the condensate at the steam trap inlet. Inlet subcooling may be expressed as degrees Fahrenheit or kelvin.

2-6 SUBCOOLED CONDENSATE

The water whose temperature is below the saturated steam temperature.

Section 3
Guiding Principles

3-1 ITEMS ON WHICH AGREEMENT SHALL BE REACHED

The parties to the test shall reach agreement on the following items prior to conducting the test:

(*a*) object of the test
(*b*) parties to the test
(*c*) test site and date
(*d*) condition of steam and condensate
(*e*) methods of measurement, instrumentation, and equipment to be used
(*f*) number, size, type, condition, source, inlet and discharge pressures, condensate temperature, and capacities of the steam trap(s) to be tested
(*g*) person who shall be responsible for the test
(*h*) written test procedure, which shall include the data to be taken and recorded to comply with the objective(s) of the test
(*i*) maximum allowable test uncertainty and method of calculating

3-2 QUALIFICATIONS OF PERSON RESPONSIBLE FOR THE TEST

The person shall have any or all of the following qualifications:

(*a*) registered Professional Engineer
(*b*) a degree from an accredited school of engineering or engineering technology
(*c*) at least two years of experience in the testing of steam traps

3-3 DUTIES OF PERSON RESPONSIBLE FOR THE TEST

The person responsible for the test shall ensure that all persons who are involved in the testing perform their duties properly. He/she shall sign and date the test results, thereby certifying, to the best of his/her knowledge, their accuracy and that the test was conducted in accordance with the written test procedures.

3-4 PROCEDURES AND TEST APPARATUS

Procedures and the arrangement of test apparatus shall be in accordance with Section 4.

3-5 TESTS

Sufficient preliminary tests shall be conducted to ensure that test personnel are completely familiar with test equipment and their respective assignments. Preliminary test shall include the recording of all data necessary to the completeness of an actual Code test.

3-6 CALIBRATION OF INSTRUMENTS

Each instrument used during the test shall be serialized or otherwise identified. Each instrument shall be calibrated in accordance with Section 4. Spare instruments, if intended for use during the test, shall also be serialized and calibrated. Records of calibrations shall be available for review by the interested parties at all times.

3-7 DATA SOURCES

The properties of steam and water used for calculations shall conform to the latest ASME Steam Tables.

3-8 ADJUSTMENTS DURING TEST

No adjustment to the steam trap shall be made during the test. Following any change or deviations of the test conditions, a sufficient period of time shall be allowed to permit the rate of flow, pressure, and temperature to attain steady conditions before readings are taken.

3-9 RECORDS AND TEST RESULTS

The test records shall include the observations, readings, recordings, and instrument calibration records required to attain the test objective(s). Copies of all records shall be furnished to each of the parties to the test. The test report shall conform to the requirements of Section 6.

3-10 CALCULATIONS

Calculations may be made using the calculation form provided or may be performed with an equivalent computer program or spreadsheet.

Section 4
Instruments and Methods of Measurement

4-1 GENERAL

If any revisions are made to the methods and guidance provided in this Code, the estimation of their effect on test uncertainty shall be made and understood by all parties to the test. This Section presents the mandatory requirements for the instruments, methods, and precautions which shall be employed. The Instrument & Apparatus (I&A) Supplements should be consulted if sufficient information is not included in this Section. By mutual agreement of the parties to the test, alternative instrumentation or instrument systems, such as flow metering or mass-flow techniques, may be used, provided that such devices or systems have demonstrated accuracy equivalent or greater to that required by this Code.

4-2 CALIBRATION OF INSTRUMENTS AND APPARATUS

Instruments and apparatus used for determination under this Code shall be calibrated in accordance with their respective I&A Supplement.

4-3 TEMPERATURE

Temperature measurements shall be carried out in accordance with accepted practices and procedures as discussed in the I&A Supplement on Temperature Measurement, PTC 19.3. Temperature shall be measured to within ±0.75°F (0.4 K). To meet this accuracy requirement, temperature shall be measured with resistance thermometers or calibrated thermocouples used with precision reading instruments. Liquid-in-glass thermometers may be used for such secondary readings as ambient temperature for manometers and barometers. If liquid-in-glass thermometers are used to measure other variables, they must be calibrated, stem corrections must be applied, and graduations must be such that a precision of 0.2°F (0.1 K) is observable. Stagnation thermometer wells shall be used or computed velocity correction applied when the average steam velocity at the sensing point exceeds 300 ft/sec (100 m/s).

When the degree of subcooling is 10°F (6 K) or less, the difference shall be measured by differential temperature sensing devices as prescribed in PTC 19.3.

4-4 PRESSURE

Pressure measurements shall be carried out in accordance with the I&A on Pressure Measurement, PTC 19.2. Pressure transmitters, electronic pressure indicators, calibrated elastic gages, or manometers shall be used for reading constant or slowly varying pressures.

(*a*) Manometers shall be of the vertical U-tube or single leg type with a minimum bore of $^5/_{16}$ in. (8 mm). Spacing between scale graduations shall not be more than $^1/_8$ in. (3 mm). In a single leg manometer, means shall be available for adjusting the scale zero while the instrument is in use. Manometers shall be selected such that the scale length and the manometer fluid density permit a reading accuracy to within ±0.5% of the measured pressure or pressure differential.

(*b*) Deadweight gages shall be selected with weights suitable for the pressure range to be measured in accordance with PTC 19.2.

(*c*) Bourdon gages or other elastic gages may be used for measurements of pressure provided that they are calibrated against a deadweight gage before and after the test. The ambient temperature of the gage during calibration shall be within 20°F (10 K) of the ambient temperature prevailing during the Code test. The diameter of the scales and the arrangement of graduations shall permit readability to within ±1.0% of the pressure being measured.

(*d*) Barometric pressure shall be measured to an accuracy within ±0.1 in. (2.5 mm) of mercury. The barometer shall be located in a stable environment at the test site and shall sense the same pressure as that of the gages and manometers used for the Code test. PTC 19.2 should be used for the procedure for care and maintenance, and the application of appropriate corrections.

(*e*) Electronic indicators or transmitters used for pressure measurement shall be 0.1% accuracy class and have a total uncertainty of 0.3% or better of calibrated span. These pressure instruments should be temperature compensated. If temperature compensation is not available, the ambient temperature at the measurement location during the test period must be compared to the temperature during calibration to determine if the decrease in accuracy is acceptable.

4-5 FLOW MEASUREMENTS

Flow measurements shall be made in accordance with the following paragraphs.

4-5.1 Weigh Tanks

Suitable tanks and scales shall be calibrated prior to use and caused to weigh to a measurement accuracy of within ±0.5% in the range of the loads to be weighed. Design, construction, calibration, and operation of weighing tanks shall be in accordance with the I&A on Weighing Scales, PTC 19.5.1.

4-5.2 Volumetric Tanks

Volumetric tanks shall be calibrated prior to use and caused to measure to an accuracy within ±0.5% in the range of volumes to be measured. Volumetric tanks shall be calibrated with weighed increments of water at a constant temperature to within ±2°F (1 K). In the use of volumetric tanks, density corrections shall be made for water temperature differences between Code test and calibration. Corrections shall be made for the change in tank volume due to thermal expansion of the tank metal and scales used to indicate volume.

4-5.3 Flowmeters

Flowmeters may be used to measure the steady flow of steam or water. For steam flow, the flow nozzle and thin-plate orifice may be used and for condensate flow, the Venturi tube may be used in addition to the flow nozzle and orifice. Measuring devices shall be calibrated prior to and after the test, and caused to measure to within an accuracy of ±3.0% of the flow being measured during the Code test. The recommendations of the I&A on Flow Measurement, PTC 19.5 series, shall be followed with reference not only to the design, construction, calibration, and use of flow measuring primary elements, but also to their location in the pipeline and the installation of the connecting piping systems between the manometer and the primary element. All computations of flow rates from observed differentials, pressures, and temperatures shall be made in accordance with the provisions of PTC 19.5 series. Primary elements shall be designed or selected such that the minimum differential pressure at any Code test output as indicated by the manometer is 10 in. (250 mm) of manometric liquid. Differential pressure caused by the primary element shall be measured by two independent differential manometer systems, which shall agree during the Code test to within ±0.2% of each other. Both manometers shall be in accordance with para. 4.4(a).

CAUTION: Some differential pressure flow measuring devices can cause flashing of near saturated liquid of the test.

4-5.4 Other Devices

Other flow-metering devices that are covered in PTC 19.5 and meet the above requirements may be used.

4-6 TIME INTERVALS

Time intervals shall be measured with stop watches or other timing devices having an interval accuracy within ±0.2% of the time interval.

4-7 STEAM LOSS TESTS

4-7.1 Test Arrangement

The recommended test arrangement for steam loss determination is shown in Fig. 1. The calorimeter tank must be filled with sufficient amount of water to result in a minimum test duration of 10 min. The final temperature should be an equal amount above ambient as the initial temperature was below ambient. The initial water temperature should be at least 15°F (8 K) below ambient. It is most important that the steam trap on the steam supply line be fully capable of maintaining a dry line to the heat exchanger. The test device should be located sufficiently below the heat exchanger to prevent condensate from backing up into the heat exchanger in the event the test device cycles infrequently. All piping and equipment shall be insulated to a minimum R value of 15 $ft^2 \cdot °F \cdot hr/Btu$ [$(0.75\ m^2 \cdot K \cdot h)/kJ$] to minimize heat loss effects.

4-7.2 Code Test Procedure for No-Load Conditions

Start with all valves closed and tanks empty.

(*a*) Open valves 1, 2, and 3 to permit drain device and test device to operate at test pressure, P_s.

(*b*) During warm-up, weigh and record mass of empty calorimeter tank, W_t; record steam pressure, P_s, and steam temperature, T_s.

(*c*) Fill calorimeter tank approximately half full with water whose temperature, T_1, is at least 15°F (8°C) below ambient temperature, T_a. Record water temperature, T_1, and mass of water plus tank, W_1.

(*d*) Rapidly close valve 3 and open valve 4. Start timing interval when valve 4 is open. Use of a three-way valve is recommended to facilitate rapid closing and opening.

(*e*) Agitate the water in the tank as necessary to ensure uniform water temperature.

(*f*) When the temperature of the water in the tank is as many degrees above ambient as the initial temperature was below, rapidly close valve 4 and open valve 3, simultaneously recording the elapsed time, then the final water temperature, T_2, and mass of water plus tank, W_2.

(*g*) When testing steam traps, the average results from three consecutive tests must agree within 10% or 1 lb/hr, whichever is greater. If this cannot be obtained, check system for integrity and increase condensate barrel capacity.

4-7.3 Code Test Procedure for Load Conditions

Load testing shall be carried out at 1% of the maximum capacity of the trap at the corresponding test pressure with a minimum of 11 lbm/hr (5 kg/h).

Start with all valves closed and both tanks empty.

(*a*) Open valves 1, 2, and 3 to permit drain device and test device to operate at test pressure, P_s.

(*b*) During warm-up, weigh and record mass of empty calorimeter tank, W_t, and record steam pressure, P_s, and steam temperature, T_s.

(*c*) Open valves 5 and 6 to allow flow of cooling water through heat exchanger to create desired condensate load on test device. After system has come to equilib-

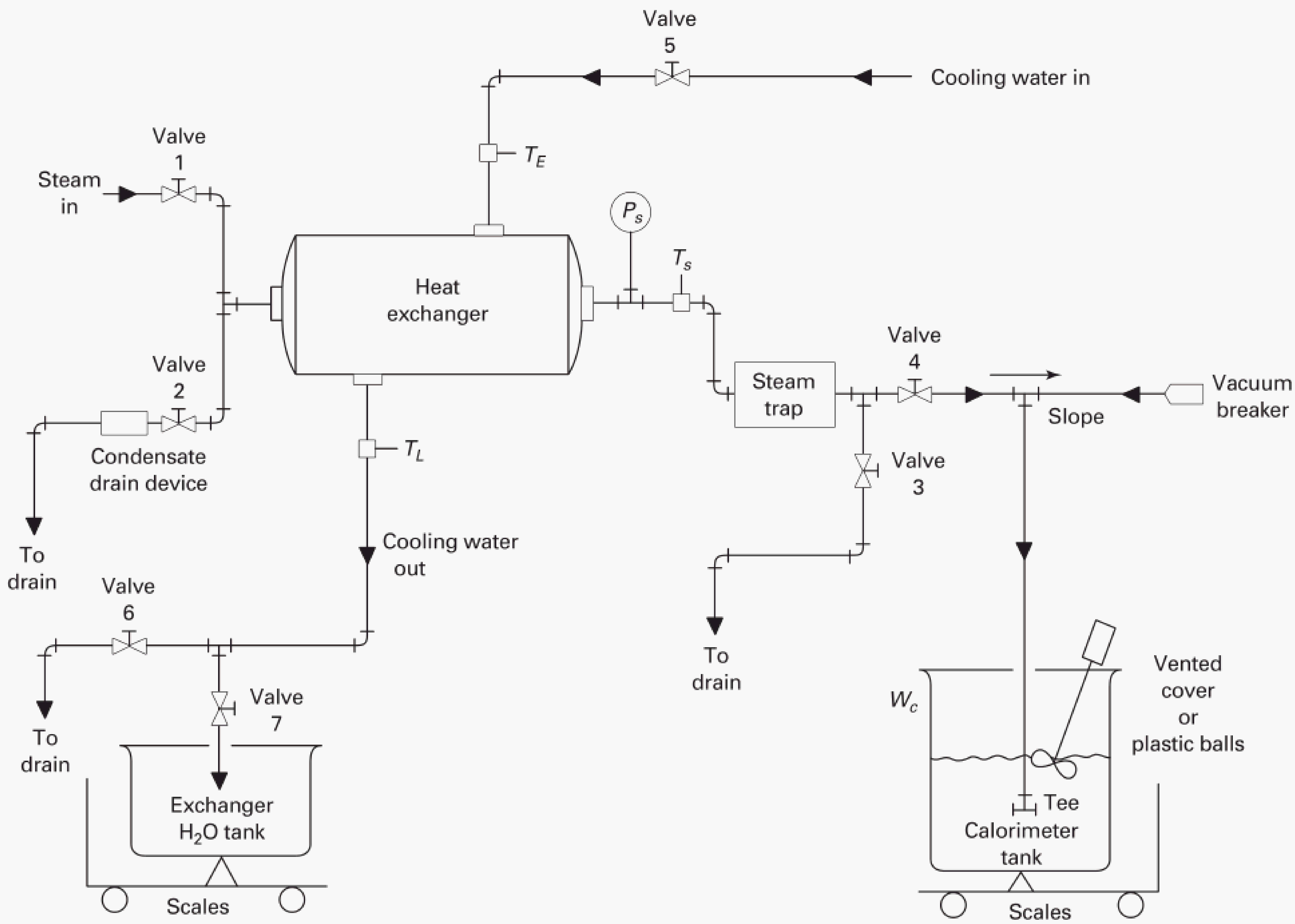


Fig. 1 Test Arrangement for Steam Loss Tests

rium, this load can be determined by closing valve 6 and opening valve 7 to permit collecting a known amount of water in a given time. The approximate condensate load on the steam trap may then be calculated by the following formula:

$$\text{Load} = \frac{(T_L - T_E)\,(W_4 - W_3) \times 3600}{(\text{time in sec})\,(h_{fg})}\ \text{lbm/hr (kg/h)}$$

where

T_E = temperatures of water entering heat exchanger, °F (°C)

T_L = temperatures of water leaving heat exchanger, °F (°C)

W_3 = initial mass of exchanger plus tank, lbm (kg)

W_4 = final mass of exchanger plus tank, lbm (kg)

h_{fg} = enthalpy of evaporation steam at steam pressure, Btu/lbm (J/kg)

time in sec = time of run on the Data Log, Form 1

(*d*) If load on trap as determined in (c) is as desired, proceed to (e) below. If not as desired, adjust valve 5 accordingly and repeat procedure (c) until desired condensate load is obtained.

(*e*) Fill calorimeter tank approximately half full with water whose temperature, T_1, is at least 15°F (8°C) below ambient temperature, T_a. Weigh and record water temperature, T_1, and mass of water plus calorimeter tank, W_1.

(*f*) Rapidly close valve 3 and open valve 4. Start timing interval when valve 4 is open. Use of a three-way valve is recommended to facilitate rapid closing and opening.

(*g*) Agitate the water in the calorimeter tank as necessary to ensure uniform water temperature.

(*h*) When the temperature of the water in the calorimeter tank is as many degrees above ambient as the initial temperature was below, rapidly close valve 4 and open valve 3, simultaneously recording the elapsed time, then the final water temperature, T_2, and mass of water plus calorimeter tank, W_2.

(*i*) When testing steam traps, average results from three consecutive tests must agree within 10% or 1 lb/hr, whichever is greater. If this cannot be obtained, check system for integrity and increase condensate tank capacity.

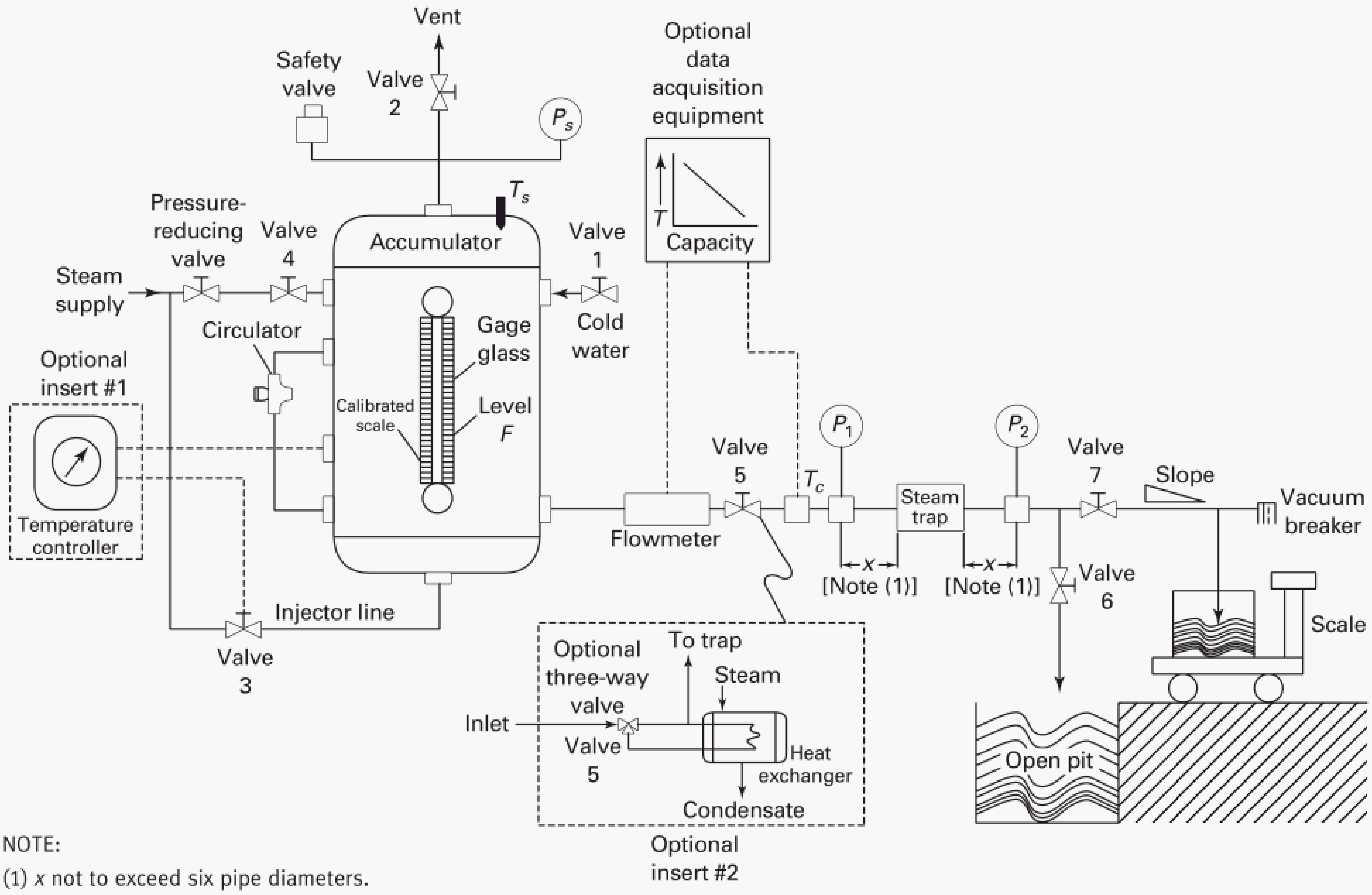
(*j*) See steam loss calculation procedure (para. 5-3).

Form 1 Data Log for Steam Loss Tests: No Loads or Condensate Load

Test no. ________ Date of test ___________ Data taken by ______________ Ambient temp., T_a ___________ Manuf. name ______________

Serial no. ________ Size ___________ Barometric pressure (Pa) ______ Description & type of device ______________ Mass of empty calorimeter tank, W_t ___________

Data		Run Numbers											Data Avg.
Item	Units												
Time													
Steam pressure, P_s													
Steam temp., T_s													
Water start temp., T_1													
Water finish temp., T_2													
Cooling water entering temp., T_E													
Cooling water leaving temp., T_L													
Water + calorimeter start weight, W_1													
Water + calorimeter finish weight, W_2													
Cooling water + tank start weight, W_3													
Cooling water + tank finish weight, W_4													



NOTE:
(1) x not to exceed six pipe diameters.

Fig. 2 Condensate Capacity Test Arrangement

4-8 CONDENSATE CAPACITY TESTS

4-8.1 Test Arrangements

The test arrangement with measurement and control device options is shown in Fig. 2. This arrangement is a composite of the equipment for three procedures. The exact equipment arrangement is dependent upon the selected procedure. Trap capacity varies with differential pressure across the steam trap and condensate temperature. Condensate temperature (T_c) and pressure at the inlet and outlet of the trap must be referenced when capacity test data are presented. See Fig. 3 for configuration of pressure taps.

4-8.2 Test Objective

The objective of the trap capacity test is to determine how steam trap capacity varies over a range of inlet pressure and condensate temperature conditions. This data may be presented either graphically or in tabular form. The discharge capacity shall be determined at a fixed inlet pressure and back pressure over a range of condensate temperatures as specified by the manufacturer or user. Trap capacity shall be determined at a condensate temperature of less than 200°F (95°C) and then at a sufficient number of additional condensate temperatures (minimum of four) to fully define the steam trap capacity characteristic up to the trap closing point.

4-8.3 Insulation

All piping and equipment shall be insulated to a minimum R value of 15 $ft^2 \cdot °F \cdot hr/Btu$ [$(0.75\ m^2 \cdot K \cdot h)/kJ$] to minimize heat loss effects.

4-8.4 Instrumentation

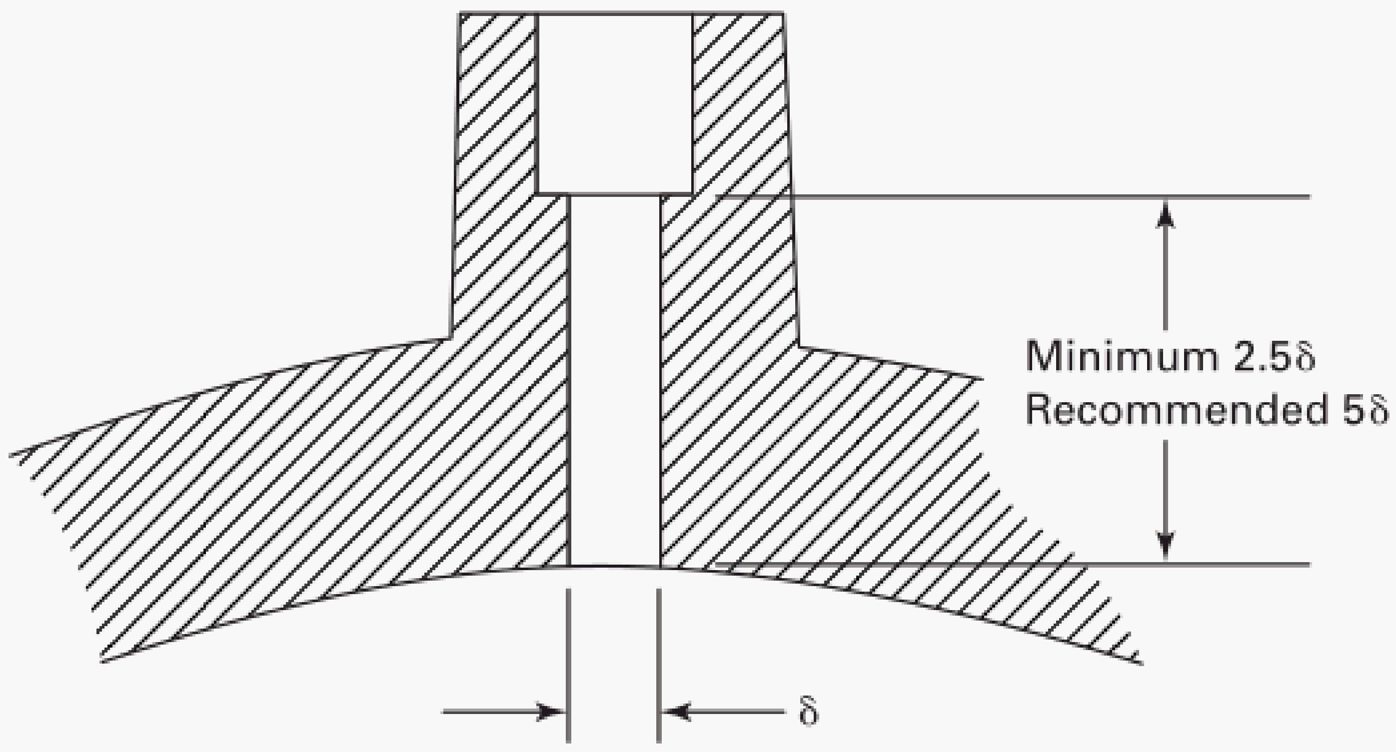
All instrumentation shall comply with paras. 4-2 through 4-6.

4-8.5 Device Under Test

The steam trap must not be modified in any way from its commercial form.

4-8.6 Code Test Procedure

Inlet pressure during the test must be maintained ±2% or ±1 psi, whichever is larger. Perform this test using one of the following three procedures, dependent on the instrumentation selected to measure the condensate capacity (see Fig. 2).



Nominal Inside Pipe Diameter, *D*, in. (mm)	Recommended Max. Diam. of Pressure Tap Holes, *δ*, in. (mm)
Under 2 (50)	1/4 (6)
2 to 3 (50 to 75)	3/8 (9)
4 to 8 (100 to 200)	1/2 (13)
10 and over (250 and over)	3/4 (19)

GENERAL NOTE: Any suitable method of making the physical connection is acceptable if the following are adhered to: fitting shall not protrude inside the pipe, and edge of hole must be clean and sharp or slightly rounded, free from burrs, wire edges, or other irregularities.

Fig. 3 Recommended Pressure Connection

(*a*) *Accumulator Level Change.* Starting with all valves closed:

(*1*) Open valves 1 and 2, and fill accumulator tank to desired level. Close valves 1 and 2.

(*2*) Open valve 4 to pressurize tank to desired pressure. Open valve 3 to heat water to desired temperature. Close valve 3. Operate the circulator or temperature controller if so equipped.

(*3*) Open valves 5 and 6 to heat the piping and steam trap. During a test run, T_c must be maintained ±5°F (2.5 K) of the average T_c recorded.

(*4*) When T_c has stabilized [when the temperature deviation is within ±2°F (1 K)], start the timing device and record T_c and the accumulator level.

(*5*) When the desired lower accumulator level is reached, stop the timing device and record the accumulator level and T_c.

(*6*) Observe and record the following on the Data Log, Form 2:

(*a*) time (h:min:sec)

(*b*) ambient temperature, T_a [°F (°C)]

(*c*) barometric pressure, P_a [psia (kPa)]

(*d*) steam pressure, P_s [psig (kPa gage)]

(*e*) steam temperature, T_s [°F (°C)]

(*f*) initial and final values of the following:

(*1*) accumulator level, *F* [ft (m)]

(*2*) condensate temperature, T_c [°F (°C)]

(*3*) inlet and outlet pressures, P_1 and P_2 [psig (kPa gage)]

(*7*) Repeat steps (1) through (6) at different condensate temperatures (T_c) to obtain at least five data sets that fully define the trap capacity characteristic.

(*8*) Use Form 3 to compute results.

(*b*) *Weigh Tank Measurement.* Starting with all valves closed:

(*1*) Open valves 1 and 2, and fill accumulator tank to desired level. Close valves 1 and 2.

(*2*) Open valve 4 to pressurize tank to desired pressure. Open valve 3 to heat water to desired temperature. Close valve 3. Operate circulator or temperature controller if so equipped.

(*3*) Fill barrel on scale so that end of discharge pipe is submerged. Measure the start mass, W_c.

(*4*) Open valves 5 and 6 to heat the piping and the steam trap. During a test run, T_c must be maintained ±5°F (2.5 K) of the average T_c recorded.

(*5*) When T_c has stabilized [when the temperature deviation is within ±2°F (1 K)], open valve 7, shut valve 6, and start the timing device.

(*6*) When sufficient condensate has been collected, simultaneously stop the timing device, open valve 6, and close valve 7.

(*7*) Observe and record the following data on the Data Log, Form 4:

(*a*) time (h:min:sec)

(*b*) ambient temperature, T_a [°F (°C)]

(*c*) barometric pressure, P_a [psia (kPa)]

(*d*) steam pressure, P_s [psig (kPa gage)]

Form 2 Data Log for Capacity Test: Accumulator Level Measurement

Test no. ________ Date of test ________ Data taken by ________ Ambient temp., T_a ________ Manuf. name ________

Serial no. ________ Size ________ Barometric pressure (Pa) ________ Description & type of device ________

Data		Run Numbers											
		1		2		3		4		5		6	
Item	Units	Start	Finish	Start	Finish	Start	Finish	Start	Finish	Start	Finish	Start	Finish
Time													
Steam pressure, P_s													
Inlet pressure, P_1													
Outlet pressure, P_2													
Steam temp., T_s													
Condensate temp., T_c													
Accumulator level, F													

Form 3 Calculation of Condensate Capacity

Accumulator Level Measurement

1. Test no. ______________ 2. Test date ______________
3. Manufacturer's name ______________
4. Type of device/model no. ______________
5. Serial no. ______________ 6. Size ______________
7. Tested by ______________ 8. Calculation by ______________
9. Capacity of accumulator tank ______________
10. Accumulator tank calibration data (reference) ______________

Test Data

11. Pressure at steam trap inlet, P_1, start	psig (kPa gage)	______
12. Pressure at steam trap outlet, P_2, start	psig (kPa gage)	______
13. Saturation temperature at P_1, T_{sat}, start	°F (°C)	______
14. Temperature of condensate, T_c, start	°F (°C)	______
15. Temperature difference, $T_{sat} - T_c$, start	°F (K)	______
16. Initial level of water in accumulator, F	ft (m)	______
17. Pressure at steam trap inlet, P_1, finish	psia (kPa)	______
18. Pressure at steam trap outlet, P_2, finish	psia (kPa)	______
19. Saturation temperature at P_1, T_{sat}, finish	°F (°C)	______
20. Temperature of condensate, T_c, finish	°F (°C)	______
21. Temperature difference, $T_{sat} - T_c$, finish	°F (K)	______
22. Final level of water in accumulator, F	ft (m)	______
23. Quantity of water discharged (reference item 10)	lbm (kg)	______
24. Time interval	sec (s)	______

Calculations

25. Differential pressure at start of test item 11 − item 12	psi (kPa)	______
26. Differential pressure at finish of test item 17 − item 18	psi (kPa)	______
27. Average differential pressure (item 25 + item 26)/2	psi (kPa)	______
28. Average subcooling (item 15 + item 21)/2	°F (K)	______
29. Capacity (item 23 × 3600)/item 24	lbm/hr (kg/h)	______

(*e*) steam temperature, T_s [°F (°C)]

(*f*) mass of condensate plus barrel at start and finish, W_c [lbm (kg)]

(*g*) initial and final values of the following:

(*1*) condensate temperature, T_c [°F (°C)]

(*2*) inlet and outlet pressure, P_1 and P_2 [psig (kPa gage)]

(*8*) Repeat (1) through (7) at different condensate temperatures (T_c) to obtain at least five data sets that fully define the trap capacity characteristic.

(*9*) Use Form 5 to compute results.

(*c*) *Flowmeter Measurement.* Starting with all valves closed:

(*1*) Open valves 1 and 2, and fill accumulator tank to desired level. Close valves 1 and 2.

(*2*) Open valve 4 to pressurize tank to desired pressure. Open valve 3 to heat water to desired starting temperature. Close valve 3. Operate circulator or temperature controller if so equipped.

(*3*) Open valves 5 and 6 to heat the piping and steam trap. During a test run, the temperature of the condensate may be increased at a rate not to exceed 10°F/min (6 K/min).

(*4*) When T_c meets the criteria above, record the flowmeter reading and T_c. Use Data Log, Form 6. Begin recording with data acquisition equipment if so equipped.

(*5*) Observe and record the following data on Form 6:

(*a*) ambient temperature, T_a [°F (°C)]

(*b*) barometric pressure, P_a [psia (kPa)]

(*c*) steam pressure, P_s [psig (kpa gage)]

(*d*) steam temperature, T_s [°F (°C)]

(*e*) flowmeter reading [lbm/hr (kg/h)]

(*f*) condensate temperature, T_c [°F (°C)]

(*g*) inlet and outlet pressure, P_1 and P_2 [psig (kPa gage)]

(*6*) Repeat (1) through (5) to obtain at least five data sets that fully define the trap capacity characteristic.

(*7*) Use Form 7 to compute results.

Form 4 Data Log for Intermittent Flow Capacity Test: Weigh Tank Measurement

Test no. ____________ Date of test ____________ Data taken by ____________ Ambient temp., T_a ____________ Manuf. name ____________

Serial no. ____________ Size ____________ Barometric pressure (Pa) ____________ Description & type of device ____________

Data		Run Numbers											
		1		2		3		4		5		6	
Item	Units	Start	Finish	Start	Finish	Start	Finish	Start	Finish	Start	Finish	Start	Finish
Time													
Steam pressure, P_s													
Inlet pressure, P_1													
Outlet pressure, P_2													
Steam temp., T_s													
Condensate temp., T_c													
Condensate + barrel weight, W_c													

Form 5 Calculation of Condensate Capacity: Weigh Tank Measurement

1. Test no. ______________________________ 2. Test date ______________________________
3. Manufacturer's name ______________________________
4. Type of device/model no. ______________________________
5. Serial no. ______________________________ 6. Size ______________________________
7. Tested by ______________________________ 8. Calculation by ______________________________
9. Scales description ______________________________

Test Data

10. Pressure at steam trap inlet, P_1, start	psig (kPa gage)	__________
11. Pressure at steam trap outlet, P_2, start	psig (kPa gage)	__________
12. Saturation temperature at P_1, T_{sat}, start	°F (°C)	__________
13. Temperature of condensate, T_c, start	°F (°C)	__________
14. Temperature difference, $T_{sat} - T_c$, start	°F (K)	__________
15. Mass of condensate plus barrel, W_c, start	lbm (kg)	__________
16. Pressure at steam trap inlet, P_1, finish	psig (kPa gage)	__________
17. Pressure at steam trap outlet, P_2, finish	psig (kPa gage)	__________
18. Saturation temperature at P_1, T_{sat}, finish	°F (°C)	__________
19. Temperature of condensate, T_c, finish	°F (°C)	__________
20. Temperature difference, $T_{sat} - T_c$, finish	°F (K)	__________
21. Mass of condensate plus barrel, W_c, finish	lbm (kg)	__________
22. Time interval	sec (s)	__________

Calculations

23. Differential pressure at start of test item 10 − item 11	psi (kPa)	__________
24. Differential pressure at finish of test item 16 − item 17	psi (kPa)	__________
25. Average differential pressure (item 23 + item 24)/2	psi (kPa)	__________
26. Average subcooling (item 14 + item 20)/2	°F (K)	__________
27. Capacity: weigh tank measurement (item 21 − item 15) × 3600/item 22	lbm/hr (kg/h)	__________

4-9 AIR AND NONCONDENSIBLE GAS REMOVAL TESTS

4-9.1 Test Arrangement/Purpose

The purpose of this test is to provide a standard means of testing steam traps fitted with automatic, fixed, or manually adjustable air vents.

The test arrangement for air and noncondensible gas removal capability is shown in Fig. 4. Two different test procedures are provided to determine the air removal capability of steam traps fitted with air vents. The first procedure provides for testing the air removal capability in a simulated start-up mode. The second procedure provides for testing in a simulated in-process operating mode. The test apparatus shown in Fig. 4 is used for both the start-up and in-process modes of testing, discharging air to atmosphere.

4-9.2 Air Vents

It should be noted that steam traps fitted with air vents (or means of bypass) should be considered a secondary means to remove air from piping systems and equipment. Good engineering practice would dictate the use of an independent air vent for piping and equipment as the primary means to remove air at start-up and/or during operation.

4-9.3 Instrumentation

All instrumentation shall comply with paras. 4-2 through 4-6. The steam trap and/or air vent must not be modified in any way from its commercial form.

4-9.4 Exceptions to Test

(*a*) Air removal test results for mechanical traps will vary depending on whether the test trap is primed or unprimed. The data sheet shall report this condition at the time of test.

(*b*) Variations to standard steam and air testing pressures shall be agreed in advance by parties to the test. Any deviations shall be noted on the test data sheet and included in the reporting of results. The steam pressure shall be 10 psig (68.9 kPa gage) greater than the air pressure in the air accumulator.

Form 6 Data Log for Intermittent Flow Capacity Test: Flowmeter Measurement

Test no. ________ Date of test ________ Data taken by ________ Ambient temp., T_a ________ Manuf. name ________

Serial no. ________ Size ________ Barometric pressure (Pa) ________ Description & type of device ________

Data		Run Numbers											
		1		2		3		4		5		6	
Item	Units	Start	Finish	Start	Finish	Start	Finish	Start	Finish	Start	Finish	Start	Finish
Time													
Steam pressure, P_s													
Inlet pressure, P_1													
Outlet pressure, P_2													
Steam temp., T_s													
Condensate temp., T_c													
Flowmeter reading, $\dot{m}$													

Form 7 Calculation of Condensate Capacity: Flowmeter Measurement

1. Test no. ______________ 2. Test date ______________
3. Manufacturer's name ______________
4. Type of device/model no. ______________
5. Serial no. ______________ 6. Size ______________
7. Tested by ______________ 8. Calculation by ______________
9. Flowmeter description ______________

Test Data

10. Pressure at steam trap inlet, P_1, start	psig (kPa gage)	________
11. Pressure at steam trap outlet, P_2, start	psig (kPa gage)	________
12. Saturation temperature at P_1, T_{sat}, start	°F (°C)	________
13. Temperature of condensate, T_c, start	°F (°C)	________
14. Temperature difference, $T_{sat} - T_c$, start	°F (K)	________
15. Pressure at steam trap inlet, P_1, finish	psig (kPa gage)	________
16. Pressure at steam trap outlet, P_2, finish	psig (kPa gage)	________
17. Saturation temperature at P_1, T_{sat}, finish	°F (°C)	________
18. Temperature of condensate, T_c, finish	°F (°C)	________
19. Temperature difference, $T_{sat} - T_c$, finish	°F (K)	________
20. Flowmeter reading, start	lbm/hr (kg/h)	________
21. Flowmeter reading, finish	lbm/hr (kg/h)	________

Calculations

22. Differential pressure at start of test item 10 − item 11	psi (kPa)	________
23. Differential pressure at finish of test item 15 − item 16	psi (kPa)	________
24. Average differential pressure (item 22 + item 23)/2	psi (kPa)	________
25. Average subcooling (item 14 + item 19)/2	°F (K)	________
26. Capacity (item 20 + item 21)/2	lbm/hr (kg/h)	________

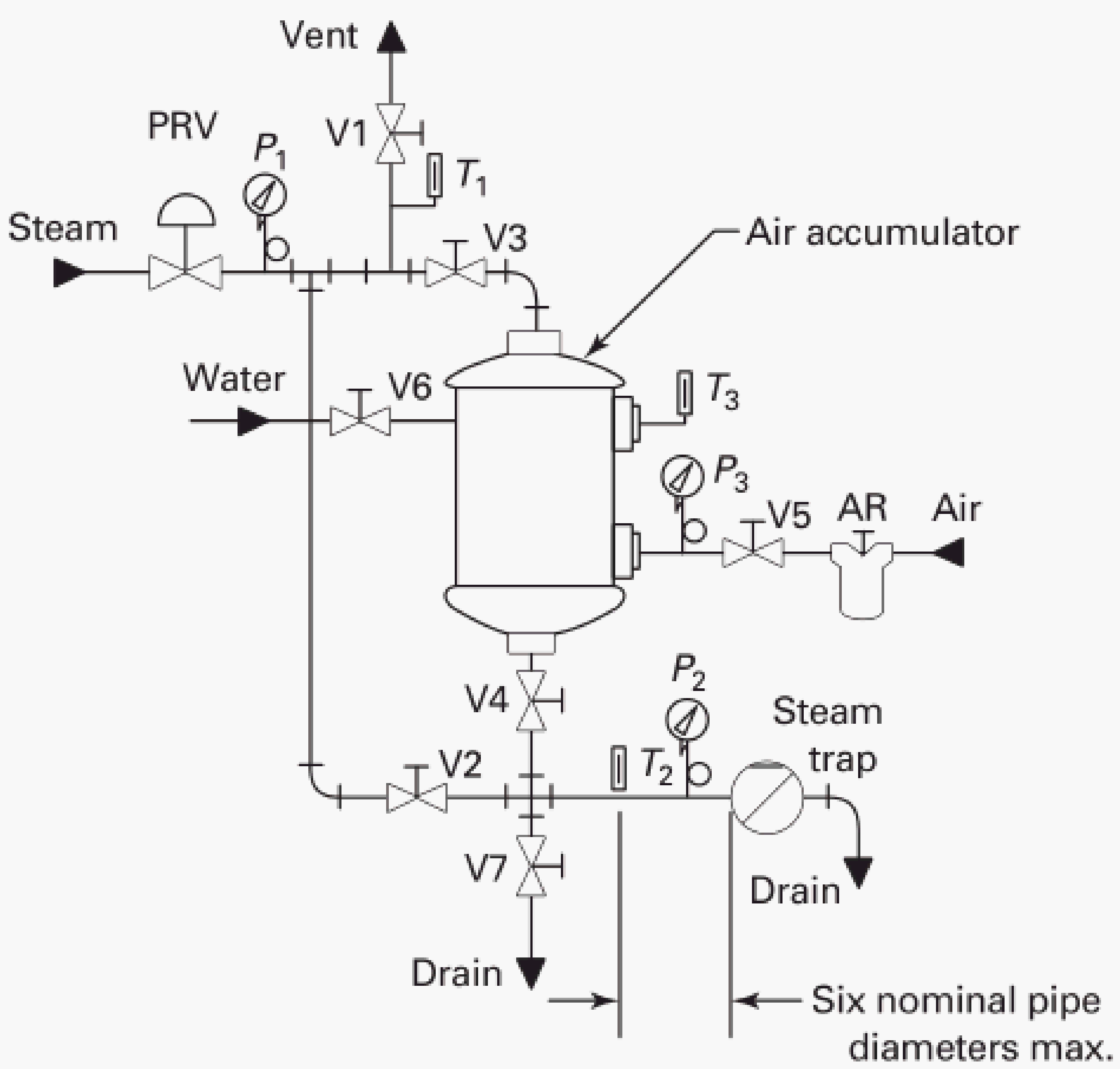


Fig. 4 Air and Noncondensible Gas Handling Capability Test Arrangement

4-9.5 Start-Up Test Procedure (See Fig. 4)

(*a*) Measure and record on Form 8 the volume (V_{AT}) contained in the air accumulator and piping bounded by valves V3, V4, V5, and V6.

(*b*) Start with all valves in the closed position and activate electronic temperature/pressure indicating/recording devices, if used.

(*c*) Open the vent valve, V1, and V3 and slowly adjust the steam pressure regulator, PRV, such that P_1 is set at the desired test pressure. Verify temperature T_1 is at saturation temperature corresponding to the test pressure P_1, and record P_1 and T_1 on Form 8.

NOTE: The vent valve can be throttled to a minimum flow to maintain stable steam pressure and temperature conditions.

(*d*) Close V3 and open valves V4, V7, and water valve V6 to cool the air accumulator tank to ambient temperature.

(*e*) Close the water valve, V6, and allow the air accumulator to drain. The air valve, V5, may be opened to facilitate draining and drying the air accumulator.

(*f*) Close valve V5 if used, and valves V4 and V7, and attach the test device.

(*g*) Open valve V5 and adjust the air accumulator pressure P_3 to approximately 80% of the steam test pressure P_1 using the air regulator (AR). Close valve V5.

Form 8 Data Log for Air and Noncondensible Removal Test

Test no. ________ **Date of test** ________ **Data taken by** ________ **Ambient temp.,** T_a ________

Serial no. ________ **Size** ________ **Description and type of device** ________

Test mode ________ **Air accumulator volume,** V_{AT} ________ ft^3 ________

Data		Run Numbers											
Item	**Units**	1											
Steam pressure, P_1													
Steam temp., T_1													
Steam pressure, P_2													
Steam temp., T_2													
Air start pressure, P_3													
Air start temp., T_3													
Test time, Δt													

Remarks: ________

(*h*) Record air pressure P_3 and temperature T_3 on Form 8. Open the inlet valve V3, the outlet valve V4, and start the test timing device simultaneously. Adjust the pressure regulating valve (PRV), if required, to maintain P_2 at the desired steam test pressure.

(*i*) Stop the test when T_2 is 10°F (6 K) less than the closing point as defined by the capacity test procedure in para. 4-8, and record the test time interval, Δt, on Form 8.

(*j*) Repeat (b) through (i) as necessary to produce three sets of observations, which result in three calculated flow rates, none of which vary from the average by more than 10%.

4-9.6 In-Process Test

(*a*) Measure and record on Form 8 the volume (V_{AT}) contained in the air accumulator and piping bounded by valves V3, V4, V5, and V6.

(*b*) Start with all valves in the closed position and activate electronic temperature indicating/recording devices, if used.

(*c*) Open valves V4, V7, and water valve V6 to cool the air accumulator to ambient temperature.

(*d*) Close the water valve, V6, and allow the air accumulator to drain. The air valve, V5, may be opened to facilitate draining and drying the air tank.

(*e*) Close valve V5 if used, and valves V4 and V7, and attach the test device.

(*f*) Open the vent valve, V1, and V3, and slowly adjust the steam pressure regulator, PRV, such that P_1 is set at the desired test pressure. Verify temperature T_1 is at saturation temperature corresponding to the test pressure, P_1, and record P_1 and T_1 on Form 8.

NOTE: The vent valve can be throttled to a minimum flow to maintain stable steam pressure and temperature conditions.

(*g*) Close V3, open valve V5, and adjust the air accumulator pressure P_3 to approximately 80% of the steam test pressure P_1 using the air regulator (AR). Close valve V5.

(*h*) Open V2 to allow the steam piping and the test device to warm up, and verify the test device is operating properly and discharging condensate.

(*i*) Record the air pressure, P_3, and temperature, T_3, on Form 8. Simultaneously close valve V2, open valves V3 and V4, and start the test timing devices. Adjust the pressure regulating valve, PRV, as required to maintain P_2 at the desired steam test pressure.

(*j*) Stop the test when T_2 is 10°F (6 K) less than the air closing point as defined by the capacity test procedure in para. 4-8, and record the test time interval, Δt, on Form 8.

(*k*) Repeat (b) through (j) as necessary to produce three sets of observations, which result in three calculated flow rates, none of which vary from the average by more than 10%.

4-9.7 Air and Noncondensible Gas Handling Capacity

Test results can be reported in actual cubic feet per minute (ACFM) or standard cubic feet per minute (SCFM). Test results shall include the air accumulator volume (V_{AT}), steam pressure (P_2), air pressure (P_3), air temperature (T_3), and test time interval (Δt).

4-9.8 Flow Rate Calculation

(*a*) The air discharge flow rate at test conditions (*ACFM*), ft³/min, is given by

$$ACFM = \frac{V_{AT}}{\Delta t}(60)$$

(*b*) The air discharge flow rate at standard conditions (*SCFM*), ft³/min, is given by

$$SCFM = \frac{V_{AT}\left(\frac{P_{3a}}{P_{STD}}\right)\left(\frac{T_{STD}}{T_{3a}}\right)60}{\Delta t}$$

where

P_{STD} = pressure at standard conditions
= 14.7 psia

P_3 = air accumulator pressure, psig

P_{3a} = air accumulator pressure, psia
= $P_3 + 14.7$

T_{STD} = temperature at standard conditions, °R
= 60°F + 460 = 520°R

T_3 = air accumulator temperature, °F

T_{3a} = air accumulator temperature, °R
= $T_3 + 460$

V_{AT} = air accumulator volume, ft³

Δt = test time interval, sec

Section 5
Computation of Results

5-1 CORRECTION OF MEASURED VARIABLES

The values of observed variables shall be corrected in accordance with instrument calibrations and, as necessary, converted to the proper units required for calculations.

5-2 USE OF FORMULA SYMBOLS

The symbols used in this Code are the ones normally associated with engineering practice in this field. In a few cases, the same symbol has different meanings in different parts of the Code, according to its application. In order to avoid confusion, each formula has been provided with its own list of definitions of symbols and units.

5-3 STEAM LOSS CALCULATIONS

(*a*) For saturated steam supplied,

$$W_L = \left[\frac{W_s(h_{fs} - h_{f1}) - W_f(h_{fs} - h_{f2}) + c_p W_t(T_2 - T_1)}{h_{fgs}}\right]\frac{3600}{\Delta t}$$

(*b*) For superheated steam supplied,

$$W_L = \Delta W/\Delta t$$

where

c_p = specific heat of barrel calorimeter, Btu/lbm-°R [J/(kg-K)]
h_{f1} = initial enthalpy of water in calorimeter, Btu/lbm (J/kg)
h_{f2} = final enthalpy of condensate in calorimeter, Btu/lbm (J/kg)
h_{fgs} = enthalpy of evaporation at steam inlet, Btu/lbm (J/kg)
h_{fs} = enthalpy of liquid at steam inlet, Btu/lbm (J/kg)
T_1 = initial water temperature, °F (°C)
T_2 = final water temperature, °F (°C)
W_f = final mass of water in calorimeter, lbm (kg)
W_L = steam loss, lbm/hr (kg/h)
W_s = initial mass of water in calorimeter, lbm (kg)
W_t = mass of tank calorimeter, lbm (kg)
W_1 = mass of calorimeter plus water, start, lbm (kg)
W_2 = mass of calorimeter plus water, finish, lbm (kg)
Δt = time interval, sec (s)
ΔW = increase in mass of water in calorimeter, lbm (kg)
$= W_2 - W_1$

See Form 9.

Section 6
Report of Test

6-1 GENERAL INFORMATION

The report of test shall be prepared to formally document the observed data and computed results. It shall contain sufficient information to prove that all Code test objectives were attained.

The procedures described in Section 5 are to be used in computing the test results.

The report of test shall include Parts I to VII as listed below.

(*a*) Part I: General Information
(*b*) Part II: Summary of Results
(*c*) Part III: Description of Steam Trap Tested
(*d*) Part IV: Observed Data and Computed Results
(*e*) Part V: Test Methods and Procedures
(*f*) Part VI: Supporting Data
(*g*) Part VII: Uncertainty Analysis

6-2 DETAILED INFORMATION

The following is a discussion of each part of the test report.

6-2.1 Part I: General Information

This part shall include the following items:

(*a*) date of test
(*b*) location of test facilities
(*c*) manufacturer's name
(*d*) manufacturer's serial number and complete identification of the steam trap
(*e*) inlet and outlet connections (stating size, pressure ratings, and type, such as threaded flanges, etc.)
(*f*) test conducted by
(*g*) representatives of parties to the test
(*h*) object of test
(*i*) fluid at steam trap inlet (saturated steam, superheated steam, wet steam, saturated water, subcooled water, air, etc.)

6-2.2 Part II: Summary of Results

This part shall include those quantities and characteristics which describe the performance of the steam trap at test conditions. The test report form for the particular test shall list the quantities, characteristics, and units of measurement required for the report.

6-2.3 Part III: Description of Steam Trap Tested

This part may include assembly drawings, manufacturing drawings, and measured dimensions if agreed to by the parties to the test. If no agreement is made, then it shall contain such descriptive information as may be furnished by the manufacturer or from his/her catalogs.

6-2.4 Part IV: Observed Data and Computed Results

This part shall include a record of data and calculations required to determine the results of the tests. The data shall have been corrected for instrument calibrations and conditions prevailing for each test run. The computation forms included in Section 5 shall be used for computing test results.

6-2.5 Part V: Test Methods and Procedures

This part shall include a detailed description of the instruments and apparatus used to measure the various quantities, and procedures for observing the characteristics of the steam trap during test.

6-2.6 Part VI: Supporting Data

This part shall include pertinent material supplementing data presented elsewhere in the report of test, whereby an independent verification of the report results can be made. This material may include, but not necessarily be limited to, the following:

(*a*) instrument calibration records
(*b*) detailed log sheets
(*c*) sample calculations

Form 9 Steam Loss Test Calculations

General Information

1. Test no. ____________ 2. Test date ____________ 3. Location ____________________________
4. Manufacturer's name ____________________ 5. Serial no. ________________________________
6. Type of trap __________________________ 7. Size __________________________________
8. Calorimeter material ____

Averaged and Corrected Test Data

9.	Mass of empty calorimeter, W_t	lbm (kg)	________
10.	Mass of calorimeter plus water, start, W_1	lbm (kg)	________
11.	Mass of calorimeter plus water, finish, W_2	lbm (kg)	________
12.	Mass added to scale, ΔW ($\Delta W = W_2 - W_1$)	lbm (kg)	________
13.	Time interval, Δt	sec (s)	________
14.	Ambient temperature, T_a	°F (°C)	________
15.	Steam temperature at trap inlet, T_s	°F (°C)	________
16.	Initial water temperature, T_1	°F (°C)	________
17.	Final temperature of water and condensate, T_2	°F (°C)	________
18.	Barometric pressure, P_a	psia (kPa)	________
19.	Steam pressure at trap inlet, P_s	psia (kPa)	________

Thermodynamic Properties

20. Reference used for specific heat data ____
21. Reference used for steam/water data ____

22.	Specific heat of calorimeter material, c_p (from item 20 for item 8 at average of items 16 and 17)	Btu/lbm-°F (J/kg)	________
23.	Initial enthalpy of water in calorimeter, h_{f1} (from item 21 at item 16)	Btu/lbm (J/kg)	________
24.	Final enthalpy of water in calorimeter, h_{f2} (from item 21 at item 17)	Btu/lbm (J/kg)	________
25.	Enthalpy of saturated liquid at trap inlet temperature, h_{fs} (from item 21 at item 15)	Btu/lbm (J/kg)	________
26.	Enthalpy of evaporation at trap inlet temperature, h_{fgs} (from item 21 at item 15)	Btu/lbm (J/kg)	________

Calculations

27. Initial mass of water in calorimeter, W_s ..... lbm (kg) ________
item 10 − item 9
______ − ______

28. Final mass of water and condensate in calorimeter, W_f ..... lbm (kg) ________
item 11 − item 9
______ − ______

29. Term $W_s\,(h_{fs} - h_{f1})$ ..... Btu (J) ________
item 27 × (item 25 − item 23)
______ × (______ − ______)

30. Term $W_f\,(h_{fs} - h_{f2})$ ..... Btu (J) ________
item 28 × (item 25 − item 24)
______ × (______ − ______)

31. Term $c_p\, W_t\,(T_2 - T_1)$ ..... Btu (J) ________
item 22 × item 9 × (item 17 − item 16)
______ × ______ × (______ − ______)

32. Steam loss, W_L ..... lbm/hr (kg/h) ________
3600 × (item 29 − item 30 + item 31)/(item 26 × item 13)
3600 × (______ − ______ + ______)/(______ × ______)

33. Water discharged with steam, W_w ..... lbm/hr (kg/h) ________

$$\frac{\text{item 12} \times 3600}{\text{item 13}} - \text{item 32}$$

34. Condensate load ..... lbm/hr (kg/h) ________

$$\frac{(T_L - T_E)(W_4 - W_3) \times 3600}{t(h_{fgs})}$$

(use values for T_L, T_E, W_4, and W_3 from Form 1)

6-2.7 Part VII: Uncertainty Analysis

When desired and agreed, an analysis of the expected uncertainty in the test data may be made following the methodology given in Appendix I. Note that the uncertainty values given in the example calculations are assumed values and do not necessarily apply to any actual test situation.

Section 7
References

The following is a list of publications referenced in this Code. The latest editions shall apply.

ASME PTC 1, General Instructions
ASME PTC 2, Definitions and Values
ASME PTC 19.2, Pressure Measurement
ASME PTC 19.3, Temperature Measurement
ASME PTC 19.5, Flow Measurement
ASME PTC 19.5.1, Weighing Scale
ASME International Steam Tables for Industrial Use

Publisher: The American Society of Mechanical Engineers (ASME), Three Park Avenue, New York, NY 10016-5990; Order Department: 22 Law Drive, Box 2300, Fairfield, NJ 07007-2300

MANDATORY APPENDIX I UNCERTAINTY ANALYSIS

I-1 GENERAL

An uncertainty analysis is a statistical evaluation method that calculates a probable error or uncertainty based on combinations of probable errors or uncertainties in individual measurements. The method given in this Appendix is intended for use by practical test technicians and engineers in the commercial or industrial steam testing laboratory. It does not give worst-case limits, and excludes the effects of blunders or systematic errors due to faulty instrumentation or test technique. To reinforce this point, the term *uncertainty* will be used rather than *error.* It should also be emphasized that this Appendix outlines a methodology which may use examples specific to certain types of traps; it is expected that variations appropriate to other types of traps will also be used.

If the probable uncertainties in individual measurements are given as n standard deviations, the analysis will give n standard deviations of total uncertainty. If the probable uncertainties in individual measurements are a P percent confidence interval, it will give a P percent confidence interval in total uncertainty.

If a quantity W is a function of measured quantities $a, b, c, \ldots$, each of which has an associated uncertainty $u_a, u_b, u_c, \ldots$, then the most general expression for the overall uncertainty of W is given by

$$U_W = \sqrt{\left(\frac{\partial W}{\partial a}\right)^2 u_a{}^2 + \left(\frac{\partial W}{\partial b}\right)^2 u_b{}^2 + \left(\frac{\partial W}{\partial c}\right)^2 u_c{}^2 + \ \ldots} \qquad (1)$$

The partial derivative with respect to any variable gives the measure of sensitivity of the overall result to small changes in that variable. In the sample worksheets in this Appendix, the partial derivative will be referred to as the *sensitivity* factor.

I-2 UNCERTAINTY IN CAPACITY TESTS

The basic capacity calculation for weigh tank tests is given by

$$W = 3600\,\frac{\Delta W}{\Delta t} \qquad (2)$$

where

W = trap capacity, lbm/hr
Δt = time interval, sec
ΔW = change in mass of the weigh tank and its contents, lbm

If a flowmeter is used, the equation is further simplified to

$$W = 3600\,\dot{m} \qquad (3)$$

where

$\dot{m}$ = flow reading, lbm/sec

Using Eq. (2) for weigh-tank measurement, the partial derivative with respect to ΔW is

$$\frac{\partial W}{\partial \Delta W} = \frac{3600}{\Delta t} \qquad (4)$$

The partial derivative with respect to Δt is

$$\frac{\partial W}{\partial \Delta t} = -\frac{3600\,\Delta W}{(\Delta t)^2} \qquad (5)$$

If we use Eq. (3) for flowmeter measurement, the partial derivative becomes simply

$$\frac{\partial W}{\partial \dot{m}} = 3600 \qquad (6)$$

However, the equations above do not include two very significant test variables. The effects of inlet pressure and condensate subcooling must also be included. For traps having a well-defined orifice size,[1] the most useful function to describe trap capacity as a function of inlet pressure (taken as gauge pressure in this case) is

$$W = AP_{IN}^{m} \qquad (7)$$

where A and m are experimentally determined coefficients reflecting the orifice size and the internal flow restrictions of the trap. Values for m range from approximately 0.3 up to 0.5 (the theoretical limit). Both A and m can be evaluated with a curve-fitting program using the results of capacity tests at varying pressures. The partial derivative with respect to inlet pressure is

$$\frac{\partial W}{\partial P_{IN}} = m\,AP_{IN}^{m-1} = \frac{m\,AP_{IN}^{m}}{P_{IN}} = \frac{mW}{P_{IN}} \qquad (8)$$

ISA standard S75.01, Flow Equations for Sizing Control Valves, gives a formula that permits analysis of the

[1] This applies to most mechanical traps where the orifice is known to be completely open and free when the trap discharges. It does not apply to the various types of thermostatic traps that may only be partly open during a normal discharge. The appropriate flow equation for these traps will be determined by their own design parameters.

Table I-1 Subcooling

Subcooling, °F, Below Saturation	Subcooling Sensitivity, °F^{-1}, at Pressure Shown, psig					
	15	30	60	125	250	500
3	0.0679	0.0630	0.0488	0.0425	0.0329	0.0214
7	0.0441	0.0383	0.0353	0.0320	0.0238	0.0174
12	0.0271	0.0279	0.0263	0.0214	0.0194	0.0150

GENERAL NOTE: The sensitivity to subcooling may also be determined directly by a capacity test with variable condensate temperatures at a constant inlet pressure. This is commonly done in the testing of thermostatic traps. When available, such actual test data would be preferred to a theoretical calculation.

effects of subcooling. With conversion for the commonly used units

$$W = 63.33C_v\sqrt{\frac{P_1 - P_{vc}}{V_f}} \tag{9}$$

where

C_v = valve flow coefficient
P_c = thermodynamic critical pressure, 3206.2 psia
P_v = inlet vapor pressure, psia
P_{vc} = pressure at the vena contracta, psia

$$P_{vc} = \left(0.96 - 0.28\sqrt{\frac{P_v}{P_c}}\right)P_v \tag{10}$$

P_1 = inlet pressure, psia
V_f = specific volume of condensate at inlet, ft^3/lbm

The inlet vapor pressure and, to a lesser extent, the specific volume are functions of the amount of subcooling. Since both of these quantities will be found from the steam tables, a numerical analysis will yield the most direct results. Let

$$T_{sc} = T_{sat} - T_1 \tag{11}$$

where

T_{sat} = saturation temperature, °F, at inlet pressure
T_{sc} = amount of subcooling, °F
T_1 = actual inlet temperature, °F

Taking any arbitrary value of C_v, such as $C_v = 1.0$, and using a range of values for P_1 and T_{sc} corresponding to actual or assumed test points, we can compute W_1 (capacity at temperature T_{sc1}) and W_2 (capacity at temperature T_{sc2}).

The *relative* subcooling sensitivity, k_{sc}, can be defined as

$$k_{sc} = \frac{W_2 - W_1}{\frac{W_2 + W_1}{2}(T_{sc2} - T_{sc1})} \tag{12}$$

Note that k_{sc} is independent of mass units. It provides us with a means to evaluate the partial derivative of W with respect to T_{sc}, which gives the overall sensitivity factor for subcooling

$$\frac{\partial W}{\partial T_{sc}} = Wk_{sc} \tag{13}$$

Values of relative subcooling sensitivity are calculated in Table I-1 for a range of inlet pressures and for various degrees of subcooling.

The overall uncertainty equation for weigh tank tests now becomes

$$U_W = \left[\left(\frac{3600}{\Delta t}\right)^2 u^2_{\Delta W} + \left(-\frac{3600\ \Delta W^2}{(\Delta t)^2}\right)^2 u^2_{\Delta t} + \left(\frac{mW}{P_{IN}}\right)^2 u^2_{P_{IN}} + (Wk_{sc})^2 u^2_{t_{sc}}\right]^{0.5} \tag{14}$$

while for flowmeter tests we have

$$U_W = \left[(3600)^2\ u^2_{\dot{m}} + \left(\frac{mW}{P_{IN}}\right)^2 u^2_{P_{IN}} + (Wk_{sc})^2 u^2_{t_{sc}}\right]^{0.5} \tag{15}$$

The equation now includes the effects of measurement uncertainties for mass, time, pressure, and temperature.[2] The worksheets for the condensate capacity test show calculations for the uncertainty of a particular capacity test. In these examples, the test accuracy specified in this Standard is assumed to be the uncertainty of the measurement within a 95% confidence interval, so that the overall uncertainty also has a 95% confidence interval.[3]

[2] The uncertainty in subcooling measurement $u_{t_{sc}}$ is, in general, not simply the uncertainty in temperature measurement. Since subcooling depends on temperature, pressure, and steam saturation properties, the uncertainty is a function of temperature measurement uncertainty, pressure measurement uncertainty, and the slope of the saturation curve $(dP/dT)_{sat}$

$$u_{t_{sc}} = \left[\left(\frac{dT}{dP}\right)^2_{sat} u^2_{P_{IN}} + u^2_{T_{IN}}\right]^{0.5}$$

The calculation of this combined uncertainty is not necessary if one uses a sensor that measures subcooling directly instead of by comparing pressure and temperature measurements.

[3] Those desiring a more rigorous treatment of uncertainty analysis are referred to PTC 19.1, Test Uncertainty, which considers the standard deviation values of multiple test measurements. It also gives methods for evaluating systematic errors (bias, calibration errors, etc.) in measurements and incorporating the effects of such systematic errors in the overall uncertainty calculation.

I-3 UNCERTAINTY IN STEAM LOSS TESTS

Restating the equation in para. 5-3(a), the steam loss with saturated steam supplied is given by

$$W_L = \left[\frac{W_s(h_{fs} - h_{f1}) - W_f(h_{fs} - h_{f2}) + c_p W_t (T_2 - T_1)}{h_{fgs}} \right] \times \frac{3600}{\Delta t} \quad (16)$$

where

c_p = specific heat of calorimeter tank, Btu/lbm-°R [J/(kg-K)]
h_{f1} = initial enthalpy of water in calorimeter, Btu/lbm (J/kg)
h_{f2} = final enthalpy of water in calorimeter, Btu/lbm (J/kg)
h_{fgs} = enthalpy of evaporation at steam inlet, Btu/lbm (J/kg)
h_{fs} = enthalpy of liquid at steam inlet, Btu/lbm (J/kg)
T_1 = initial water temperature, °F (°C)
T_2 = final water temperature, °F (°C)
W_f = final mass of water in calorimeter, lbm (kg)
W_L = steam loss, lbm/hr (kg/h)
W_s = initial mass of water in calorimeter, lbm (kg)
W_t = mass of calorimeter tank, lbm (kg)
W_1 = mass of calorimeter plus water, start, lbm (kg)
W_2 = mass of calorimeter plus water, finish, lbm (kg)
Δt = time interval, sec (s)

Noting that h_{fs} and h_{fgs} are functions of steam inlet temperature T_s, h_{f2} is a function of T_2, and h_{f1} is a function of T_1, we can rearrange this equation to separate the functions of the various temperatures as much as possible as follows:

$$W_L = \left[(W_s - W_f)\left(\frac{h_{fs}}{h_{fgs}}\right) + \frac{W_f h_{f2} + c_p W_t T_2}{h_{fgs}} - \frac{W_s h_{f1} + c_p W_t T_1}{h_{fgs}} \right] \frac{3600}{\Delta t} \quad (17)$$

The partial derivatives of the various thermodynamic functions are best determined by numerical evaluation in the region of interest. The four functions to be evaluated are

$$k_{f1} = \frac{\partial h_{f1}}{\partial T_1}$$

$$k_{f2} = \frac{\partial h_{f2}}{\partial T_2}$$

$$k_{s1} = \frac{\partial (h_{fs}/h_{fgs})}{\partial T_s}$$

$$k_{s2} = \partial (\frac{1/h_{fgs})}{\partial T_s}$$

The overall uncertainty of the steam loss test can now be found from the partial derivatives and the uncertainty values related to the eight variables, W_s, W_f, T_s, T_2, c_p, W_t, T_1, and Δt

$$U_{W_L} = \begin{bmatrix} \left(\frac{\partial W_L}{\partial W_s}\right)^2 u_{W_s}^2 + \left(\frac{\partial W_L}{\partial W_f}\right)^2 u_{W_f}^2 \\ + \left(\frac{\partial W_L}{\partial T_s}\right)^2 u_{Ts}^2 + \left(\frac{\partial W_L}{\partial T_2}\right)^2 u_{T_2}^2 \\ + \left(\frac{\partial W_L}{\partial c_p}\right)^2 u_{c_p}^2 + \left(\frac{\partial W_L}{\partial W_t}\right)^2 u_{W_t}^2 \\ + \left(\frac{\partial W_L}{\partial T_1}\right)^2 u_{T_1}^2 + \left(\frac{\partial W_L}{\partial \Delta t}\right)^2 u_{\Delta t}^2 \end{bmatrix}^{0.5} \quad (18)$$

Now, referring back to Eq. (17), the partials of W_L with respect to the eight variables are

$$W_s\text{: } \partial \frac{W_L}{\partial W_s} = \left(\frac{h_{fs} - h_{f1}}{h_{fgs}}\right) \frac{3600}{\Delta t} \quad (19)$$

$$W_f\text{: } \frac{\partial W_L}{W_f} = \left(\frac{-h_{fs} + h_{f2}}{h_{fgs}}\right) \frac{3600}{\Delta t} \quad (20)$$

$$T_s\text{: } \partial \frac{W_L}{\partial T_s} = \left\{ (W_f - W_s)k_{s1} + [W_f h_{f2} + c_p W_t (T_2 - T_1) - W_s h_{f1}]k_{s2} \right\} \frac{3600}{\Delta t} \quad (21)$$

$$T_2\text{: } \frac{\partial W_L}{\partial T_2} = \left(\frac{W_f k_{f2} + c_p W_t}{h_{fgs}}\right) \frac{3600}{\Delta t} \quad (22)$$

$$c_p\text{: } \frac{\partial W_L}{\partial c_p} = \frac{W_t (T_2 - T_1)}{h_{fgs}} \left(\frac{3600}{\Delta t}\right) \quad (23)$$

$$W_t\text{: } \frac{\partial W_L}{\partial W_t} = \frac{c_p (T_2 - T_1)}{h_{fgs}} \left(\frac{3600}{\Delta t}\right) \quad (24)$$

$$T_1\text{: } \frac{\partial W_L}{\partial T_1} = \left(\frac{W_s k_{f1} + c_p W_t}{h_{fgs}}\right) \frac{3600}{\Delta t} \quad (25)$$

Δt: From Eq. (17)

$$W_L = [\cdots] \left(\frac{3600}{\Delta t}\right)$$

$$\frac{\partial W_L}{\partial \Delta t} = -[\cdots] \left(\frac{3600}{\Delta t^2}\right)$$

(The terms within square brackets are common to both equations, and are omitted for clarity.)

$$\frac{\partial W_L}{\partial \Delta t} = -\frac{W_L}{\Delta t} \quad (26)$$

At this point it would be possible to insert Eqs. (19) through (26) into Eq. (18). However, it is more useful to enter these quantities into a data sheet so step-by step calculations can be made. It is even more useful to have a spreadsheet program set up to do the calculations and look up the thermodynamic properties. Forms I-1 through I-4 show examples of the computation using a spreadsheet arranged in the manner of the usual worksheets. Readers following carefully through the examples given may discover what appear to be small numerical discrepancies. Please remember that the spreadsheets use many significant figures internally, even though the results may be displayed with a much lower precision. This is also a warning about the effects of rounding manually calculated results too soon.

Form I-1 Condensate Capacity Test With Uncertainty Analysis for Weigh Tank Measurement

General Data

1. Test no. ______________________ 2. Test date ______________________
3. Manufacturer's name ______________________
4. Type of trap or model no. ______________________
5. Serial no. ______________________ 6. Size ______________________
7. Tested by ______________________ 8. Calculation by ______________________
9. Scales description ______________________

Test Data

		Observed Value
10. Pressure at steam trap inlet, P_1, start	psig	99.5
11. Pressure at steam trap outlet, P_2, start	psig	9
12. Saturation temperature at P_1, T_{sat}, start	°F	337.6
13. Temperature of condensate, T_c, start	°F	330
14. Temperature difference, $T_{sat} - T_c$, start	°F	7.6
15. Mass of condensate plus barrel, W_c, start	lbm	245
16. Pressure at steam trap inlet, P_1, finish	psig	99
17. Pressure at steam trap outlet, P_2, finish	psig	9.5
18. Saturation temperature at P_1, T_{sat}, finish	°F	337.2
19. Temperature of condensate, T_c, finish	°F	331
20. Temperature difference, $T_{sat} - T_c$, finish	°F	6.2
21. Mass of condensate plus barrel, W_c, finish	lbm	345
22. Time interval	sec	87

Capacity and General Calculations

25. Average differential pressure = (#10 − #11 + #16 − #17) / 2	psig	90.0
26. Average subcooling = (#14 + #20) / 2	°F	6.9
27. Capacity = (#21 − #15) × 3600 / #22	lbm/hr	4,138
28. Average inlet pressure = (#10 + #16) / 2	psig	99.25
29. Average sat. temp. = (#12 + #18) / 2	°F	337.4

Uncertainty Calculations

		Sensitivity, S	Uncertainty, u	$S^2 \times u^2$
30. Mass measurement sensitivity = 3600 / #22		41.3793103	. . .	. . .
31. Mass measurement uncertainty = 0.005 (#15 + #21) / 2		. . .	1.475	3,725.2
32. Time interval sensitivity = 3600 (#21 − #15) / $(\#22)^2$		47.5624257	. . .	. . .
33. Time interval uncertainty = 0.002 (#22)		. . .	0.174	68.5
36. Inlet pressure exponent m	0.38			
37. Inlet pressure sensitivity = #36 × #27 / #28		15.8429601	. . .	. . .
38. Inlet pressure measurement uncertainty = 0.01 × #28		. . .	0.9925	247.2
39. Relative subcooling sensitivity, k_{sc}	0.033			
40. Subcooling sensitivity = #39 × #27		136.551724	. . .	. . .
41. Subcooling measurement uncertainty		. . .	0.75	10,488.6
42. Sum of $S^2 \times u^2$ terms				14,529.5
43. Overall uncertainty = $(\#42)^{0.5}$				120.5 lbm/hr
44. Relative overall uncertainty = #43 / #27				2.91%

GENERAL NOTE: In order to maintain parallel item numbering in Forms I-1 and I-2, some item numbers have been skipped in this Form or the other.

Form I-2 Condensate Capacity Test With Uncertainty Analysis for Flowmeter Measurement

General Data

1. Test no. ______________ 2. Test date ______________
3. Manufacturer's name ______________
4. Type of trap or model no. ______________
5. Serial no. ______________ 6. Size ______________
7. Tested by ______________ 8. Calculation by ______________
9. Flowmeter description ______________

Test Data

		Observed Value
10. Pressure at steam trap inlet, P_1, start	psig	99.5
11. Pressure at steam trap outlet, P_2, start	psig	9
12. Saturation temperature at P_1, T_{sat}, start	°F	337.6
13. Temperature of condensate, T_c, start	°F	330
14. Temperature difference, $T_{sat} - T_c$, start	°F	7.6
16. Pressure at steam trap inlet, P_1, finish	psig	99
17. Pressure at steam trap outlet, P_2, finish	psig	9.5
18. Saturation temperature at P_1, T_{sat}, finish	°F	337.2
19. Temperature of condensate, T_c, finish	°F	331
20. Temperature difference, $T_{sat} - T_c$, finish	°F	6.2
23. Flowmeter reading, start	lbm/sec	1.150
24. Flowmeter reading, finish	lbm/sec	1.147

Capacity and General Calculations

25. Average differential pressure = (#10 − #11 + #16 − #17) / 2	psig	90.0
26. Average subcooling = (#14 + #20) / 2	°F	6.9
27. Capacity = [(#23 + #24)/2] × 3600	lbm/hr	4,135
28. Average inlet pressure = (#10 + #16) / 2	psig	99.25
29. Average sat. temp. = (#12 + #18) / 2	°F	337.4

Uncertainty Calculations

		Sensitivity, S	Uncertainty, u	$S^2 \times u^2$
34. Flowmeter measurement sensitivity		3600	...	...
35. Flowmeter measurement uncertainty = 0.03 (#23 + #24) / 2		...	0.034	15,385.4
36. Inlet pressure exponent m	0.38			
37. Inlet pressure sensitivity = #36 × #27 / #28		15.8302065	...	...
38. Inlet pressure measurement uncertainty = 0.01 × #28		...	0.9925	246.9
39. Relative subcooling sensitivity, k_{sc}	0.033			
40. Subcooling sensitivity = #39 × #27		136.4418	...	...
41. Subcooling measurement uncertainty		...	0.75	10,471.7
42. Sum of $S^2 \times u^2$ terms				26,104.0
43. Overall uncertainty = $(\#42)^{0.5}$				161.6 lbm/hr
44. Relative overall uncertainty = #43 / #27				3.91%

GENERAL NOTE: In order to maintain parallel item numbering in Forms I-1 and I-2, some item numbers have been skipped in this Form or the other.

Form I-3 Steam Loss Test: Alternative Method, With Uncertainty Analysis

General Data

1. Test no. ______________ 2. Test date ______________
3. Location ______________
4. Mfr's name ______________ 5. Serial no. ______________
6. Trap type/model no. ______________ 7. Size ______________
8. Calorimeter material S. S.
Tested by ______________ Calculation by ______________

Averaged and Corrected Test Data

			Observed Value
9.	Mass of empty calorimeter, W_t	lbm	25.25
10.	Mass of calorimeter plus water, start, W_1	lbm	80.437
11.	Wt. of calorimeter and water, finish, $W_2 = W_1 + \Delta W$	lbm	84.75
12.	Mass added to scale, ΔW	lbm	4.313
13.	Time interval, Δt	sec	1,626
14.	Ambient temperature, T_a	°F	101
15.	Steam temperature at trap inlet, T_s	°F	444
16.	Initial water temperature, T_1	°F	81
17.	Final temp. of water and condensate, T_2	°F	121
18.	Barometric pressure, P_a	in. Hg	29.42
18a.		psia	14.45
19.	Steam pressure at trap inlet, P_s	psig	400
19a.		psia	414.45

Thermodynamic Properties

20.	Reference used for specific heat data	Machinery's Handbook 21st Ed.	
21.	Reference used for steam/water data	ASME Steam Tables, 1967	
22.	Specific heat of calorimeter material, c_p at avg. temp. $(T_1 + T_2) / 2 = 101$	Btu/lbm-°F	0.117
23.	Initial enthalpy of water in calorimeter, h_{f1} at temperature T_1 (#16)	Btu/lbm	49.035
24.	Final enthalpy of water in calorimeter, h_{f2} at temperature T_2 (#17)	Btu/lbm	88.96
25.	Enthalpy of saturated liquid at trap inlet temp., h_{fs} at temperature T_s (#15)	Btu/lbm	423.48
26.	Enthalpy of evaporation at trap inlet temp., h_{fgs} at temperature T_s (#15)	Btu/lbm	781.04

Steam Loss Calculations

27.	Initial mass of water in calorimeter, W_s = #10 − #9	lbm	55.187
28.	Final mass of water in calorimeter, W_f = #12 − #9	lbm	59.5
29.	Term $W_s\,(h_{fs} - h_{f1})$ = #27 × (#25 − #23)	Btu	20,664.50
30.	Term $W_f\,(h_{fs} - h_{f2})$ = #28 × (#25 − #24)	Btu	19,903.94
31.	Term $c_p\,W_t\,(T_2 - T_1)$ = #22 × #9 × (#17 − #16)	Btu	118.17
32.	Steam loss, W_L = 3600(#29 − #30 + #31) / (#26 × #13)	lbm/hr	2.49
33.	Water discharged with steam = (#12 × 3600) / #13 − #32	lbm/hr	7.06
34.	Condensate load		N/A

Form I-3 Steam Loss Test: Alternative Method, With Uncertainty Analysis (Cont'd)

Uncertainty Calculations

Thermodynamic Functions of T_1, T_2, and T_s:

35. $k_{f1} = \dfrac{\partial h_{f1}}{\partial T_1}$ At T_1 = 81°F, k_{f1} = 0.998 Btu/lbm-°F

36. $k_{f2} = \dfrac{\partial h_{f2}}{\partial T_2}$ At T_2 = 121°F, k_{f2} = 1.000 Btu/lbm-°F

37. $k_{s1} = \dfrac{\partial (h_{fs}/h_{fgs})}{\partial T_s}$ At T_s = 444°F, k_{s1} = 0.002 24/°F

38. $k_{s2} = \dfrac{\partial (1/h_{fgs})}{\partial T_s}$ At T_s = 444°F, k_{s2} = 1.84E-06 lbm/Btu-°F

Variable	Formula for Sensitivity or Uncertainty	Sensitivity, S	Uncertainty, u	$S^2 \times u^2$
ΔW	S = [(#25 + #24)/#26](3600/#13)	1.452619	...	...
		...	0.28	0.16543198
W_s	S = [(#24 − #23)/#26](3600/#13)	−0.113176	...	...
	u = 0.005 (#27)	...	0.28	0.00097526
T_s	S = {(#12)(#37) + [(#27 + #12) × #24 + #31 − (#29 × #23)](#38)}(3600/#13)			
		0.0324031	...	...
		...	0.75	0.0005906
T_2	S = [(#28 × #36 + #22 × #9)/#26](3600/#13)	0.1770397	...	...
		...	0.75	0.01763047
c_p	S = [#9(#17 − #16)/#26](3600/#13)	2.8630574	...	...
		...	0.005	0.00020493
W_t	S = [#22(#17 − #16)/#26](3600/#13)	0.0132664	...	...
	u = 0.005 (#9)	...	0.13	2.8053E-06
T_1	S = −[(#27 × #35 + #22 × #9)/#26](3600/#13)	−0.008725	...	...
		...	0.75	4.2818E-05
ΔT	S = #32/#13	−0.001532	...	...
	u = 0.002 (#13)	...	3.3	2.4819E-05
	$\Sigma(P^2 \times u^2)$ = sum of $P^2 \times u^2$ terms			0.18490368
	U_W = overall uncertainty in $W_L = [\Sigma(P^2 \times u^2)]^{0.5}$			0.43 lb/hr
	Relative uncertainty = U_W/W_L			17.3%

It is also worthwhile to point out that the steam loss test involves measuring and calculating the difference of two large but nearly equal quantities. This is a situation that most lab people would prefer to avoid, but unfortunately it is inherent in the steam loss test method. Low values of steam loss will almost inevitably be associated with relatively large uncertainties, as is shown in the example included here.

I-4 UNCERTAINTY IN AIR VENTING TESTS

Two calculations are made for the air venting test

$$ACFM = \frac{60(V_{AT})}{\Delta t} \tag{27}$$

$$SCFM = \frac{60\ V_{AT} P_{3a} T_{std}}{\Delta t\ P_{std} T_{3a}} \tag{28}$$

where

P_{std} = pressure at standard conditions = 14.7 psia
P_{3a} = air accumulator absolute pressure, psia
T_{std} = temperature at standard conditions = 520°R
T_{3a} = air accumulator temperature, °R
V_{AT} = accumulator tank volume, ft^3
Δt = test time interval, sec

Considering first the actual discharge rate ($ACFM$) from Eq. (27), the partial derivative with respect to V_{AT} is

$$\frac{\partial(ACFM)}{\partial V_{AT}} = \frac{60}{\Delta t} = \frac{ACFM}{V_{AT}} \tag{29}$$

The partial derivative with respect to Δt is

$$\frac{\partial(ACFM)}{\partial \Delta t} = \frac{-60\ V_{AT}}{(\Delta t)^2} = \frac{-ACFM}{\Delta t} \tag{30}$$

Form I-4 Air Venting Test With Uncertainty Analysis

General Data

1. Test no. ________________ 2. Test date ________________
3. Manufacturer's name XX
4. Type of trap or model no. F & T
5. Serial no. ________________ 6. Size 1/2"
7. Tested by ________________ 8. Calculation by ________________
9. Type of test (start-up or in-process) Start-up

Test Data

		Observed Value
10. Volume of air accumulator tank, V_{AT}	ft^3	1.20
11. Air accumulator gauge pressure, P_3	psig	100
12. Air accumulator absolute pressure, P_{3a}	psia	114.7
13. Air accumulator temperature, T_3	°F	86
14. Air accumulator absolute temperature, T_{3a}	°R	546
15. Test time interval, Δt	sec	88

Constants

16. Pressure at standard conditions, P_{std}	psia	14.7
17. Temperature at standard conditions, T_{std}	°R	520

Air Discharge Rate Calculations

18. Air discharge flow rate at test conditions

$$ACFM = \frac{60\ V_{AT}}{\Delta t}$$ ft^3/min 0.82

19. Air discharge flow rate at standard conditions

$$SCFM = \frac{60\ V_{AT}}{\Delta t}\left(\frac{P_{3a}}{P_{std}}\right)\left(\frac{T_{std}}{T_{3a}}\right)$$ ft^3/min 6.08

Uncertainty Calculations

Parameters for *ACFM*:		Sensitivity, S	Uncertainty, u	$S_2 \times u^2$
20. Accumulator volume sensitivity = $ACFM$ / V_{AT}		0.6818	...	...
21. Accumulator volume uncertainty		...	0.025	0.000291
22. Test time sensitivity = $-ACFM$ / Δt		−0.0093	...	...
23. Test time uncertainty		...	3	0.000778
24. Sum of $S^2 \times u^2$ terms				0.001069
25. Overall uncertainty in $ACFM$ = $(\#24)^{0.5}$	0.033 ft^3/min			
26. Relative uncertainty in $ACFM$ = #25 / #18	4.0%			

Parameters for *SCFM*:			
27. Accumulator volume sensitivity = $SCFM$ / V_{AT}	5.0667	...	...
28. Accumulator volume uncertainty	...	0.025	0.016045
29. Test time sensitivity = $-SCFM$ / Δt	−0.0691	...	...
30. Test time uncertainty	...	3	0.042963
31. Accumulator pressure sensitivity = $SCFM$ / P_{3a}	0.0530	...	...
32. Accumulator pressure uncertainty	...	1	0.002810
33. Accumulator temperature sensitivity = $-SCFM$ / T_{3a}	−0.0111	...	...
34. Accumulator temperature uncertainty	...	0.75	0.000070
35. Sum of $S^2 \times u^2$ terms			0.061887
36. Overall uncertainty in $SCFM$ = $(\#31)^{0.5}$			0.249 ft^3 / min
37. Relative uncertainty in $SCFM$ = #32 / #19			4.1%

The overall uncertainty in *ACFM* is given by

$$U_{ACFM} = ACFM\left[\left(\frac{1}{V_{AT}}\right)^2(u_{V_{AT}})^2 + \left(\frac{-1}{\Delta t}\right)^2(u_{\Delta t})^2\right]^{0.5} \quad (31)$$

Now we turn to the discharge rate at "standard" conditions given by Eq. (28). At this point the pattern of partial derivatives for this simple first-degree function should be clear. The partial derivative with respect to the four variables can be written easily. Note that P_{std} and T_{std} are fixed coefficients, not variables.

$$V_{AT}: \frac{\partial(SCFM)}{\partial V_{AT}} = \frac{SCFM}{V_{AT}} \quad (32)$$

$$\Delta t: \frac{\partial(SCFM)}{\partial(\Delta t)} = \frac{-SCFM}{\Delta t} \quad (33)$$

$$P_{3a}: \frac{\partial(SCFM)}{\partial(P_{3a})} = \frac{SCFM}{P_{3a}} \quad (34)$$

$$T_{3a}: \frac{\partial(SCFM)}{\partial T_{3a}} = \frac{-SCFM}{T_{3a}} \quad (35)$$

The overall uncertainty in *SCFM* is given by

$$U_{SCFM} = SCFM\left[\left(\frac{1}{V_{AT}}\right)^2(u_{V_{AT}})^2 + \left(\frac{-1}{\Delta t}\right)^2(u_{\Delta t})^2 + \left(\frac{1}{P_{3a}}\right)^2(u_{P_{3a}})^2 + \left(\frac{-1}{T_{3a}}\right)^2(u_{P_{3a}})^2\right]^{0.5} \quad (36)$$

The calculations given in Eqs. (29) through (36) can be evaluated manually, or they can be inserted into a spreadsheet as shown in the example included in this Appendix. Like the other examples given, this is based upon actual tests. The relatively large uncertainty associated with the test time interval illustrates one of the known difficulties with the air venting test, namely, determining exactly when the trap inlet temperature has reached the desired final value.

However, please note that the uncertainties given here are not intended to define a value of uncertainty that might apply to any other test. The object of all these examples is to show how the calculation is performed.

NONMANDATORY APPENDIX A
CONVERSION TABLES

Table A-1 SI (Metric) Conversions

Quantity	Conversion From	Conversion To	Multiplication Factor	
Acceleration, linear	ft/sec^2	m/s^2	3.048 [Note (1)]	E − 01
	standard gravity	m/s^2	9.806 65 [Note (1)]	E + 00
Area	$in.^2$	m^2	6.451 6	E − 04
	ft^2	m^2	9.290 304 [Note (1)]	E − 02
Coefficient of thermal expansion	$°R^{-1}$	K^{-1}	1.8 [Note (1)]	E + 00
Density	lbm/ft^3	kg/m^3	1.601 846	E + 01
	$slugs/ft^3$	kg/m^3	5.153 788	E + 02
Energy, work, heat	Btu (IT)	J	1.055 056	E + 03
	ft-lbf	J	1.355 818	E + 00
Flow rate, mass	lbm/sec	kg/s	4.535 924	E − 01
	lbm/min	kg/s	7.559 873	E − 03
	lbm/hr	kg/s	1.259 979	E − 04
	slugs/sec	kg/s	1.459 390	E + 01
Flow rate, volume	ft^3/min	m^3/s	4.719 474	E − 04
	ft^3/sec	m^3/s	2.831 685	E − 02
	gallons (U.S. liquid)/min	m^3/s	6.309 020	E − 05
Gas constant	Btu/lbm-°R	J/(kg·K)	4.186 8 [Note (1)]	E + 03
	ft-lbf/lbm-°R	J/(kg·K)	5.380 320	E + 00
Heat transfer coefficient	$Btu/hr\text{-}ft^2\text{-}°R$	$W/(m^2·K)$	5.678 263	E + 00
Length	in.	m	2.54 [Note (1)]	E − 02
	ft	m	3.048 [Note (1)]	E − 01
Mass	lbm (avoirdupois)	kg	4.535 924	E − 01
	slug	kg	1.459 390	E + 01
Pressure	standard atmosphere	Pa	1.013 25 [Note (1)]	E + 05
	bar	Pa	1 [Note (1)]	E + 05
	lbf/ft^2	Pa	4.788 026	E + 01
	$lbf/in.^2$	Pa	6.894 757	E + 03
Rotational frequency	min^{-1}	s^{-1}	1.666 667	E − 02
Specific enthalpy	Btu/lbm	J/kg	2.326	E + 03
Specific entropy	Btu/lbm-°R	J/(kg·K)	4.186 8 [Note (1)]	E + 03
Specific heat	Btu/lbm-°R	J/(kg·K)	4.186 8 [Note (1)]	E + 03
Specific volume	ft^3/lbm	m^3/kg	6.242 797	E − 02
Temperature interval	°F	°C	5.555 556	E − 01
Temperature, measured	°F	°C	$t_C = (t_F - 32)/1.8$	
Temperature, thermodynamic	°C	K	$T_K = t_C + 273.15$	
	°F	K	$T_K = (t_F + 459.67)/1.8$	
	°R	K	$T_K = T_R/1.8$	
Thermal conductivity	$Btu\text{-}ft/hr\text{-}ft^2\text{-}°R$	W/(m·K)	1.730 735	E + 00
Time	hr	s	3.6 [Note (1)]	E + 03
	min	s	6 [Note (1)]	E + 01
Velocity	ft/hr	m/s	8.466 667	E − 05
	ft/min	m/s	5.08 [Note (1)]	E − 03
	ft/sec	m/s	3.048 [Note (1)]	E − 01
Volume	gallon (U.S. liquid)	m^3	3.785 412	E − 03
	ft^3	m^3	2.831 685	E − 02
	$in.^3$	m^3	1.638 706	E − 05
	liter	m^3	1 [Note (1)]	E − 03

GENERAL NOTE: The factors are written as a number greater than one and less than ten with six decimal places. The number is followed by the letter E (for exponent), a plus or minus symbol, and two digits that indicate the power of 10 by which the number must be multiplied to obtain the correct value. For example, 3.785 412 E − 03 is $3.785\ 412 \times 10^{-3}$ or 0.003 785 412.

NOTE:

(1) Exact relationship in terms of the base units.

Table A-2 Conversion Factors for Pressure (Force/Area)

To obtain → / Multiply, by ↓	atm	bar	$\frac{lbf}{in.^2}$	in. Hg (0°C)	ft H_2O (20°C)	mm Hg (0°C)	kPa
atm	1	1.013 25	$\frac{1\ 013\ 250 \times 2.54^2}{980.665 \times 453.592\ 37}$ = 14.695 948 8	$\frac{1\ 013\ 250/980.665}{13.595\ 088\ 9 \times 2.54}$ = 29.921 280 0	$\frac{1\ 013\ 250/980.665}{0.998\ 278\ 282 \times 30.48}$ = 33.957 002 9	$\frac{10\ 132\ 500/980.665}{13.595\ 088\ 9}$ = 760.000 512	101.325
bar	$\frac{1.0}{1.013\ 25}$ = 0.986 923 267	1	$\frac{2.54^2 \times 10^6}{980.665 \times 453.592\ 37}$ = 14.503 773 8	$\frac{10^6/980.665}{13.595\ 088\ 9 \times 2.54}$ = 29.530 007 4	$\frac{10^6/980.665}{0.998\ 278\ 282 \times 30.48}$ = 33.512 956 2	$\frac{10^7/980.665}{13.595\ 088\ 9}$ = 750.062 188	100
$\frac{lbf}{in.^2}$	$\frac{980.665 \times 453.592\ 37}{1\ 013\ 250 \times 2.54^2}$ = 0.068 045 963 9	$\frac{980.665 \times 453.592\ 37}{2.54^2 \times 10^2}$ = 0.068 947 572 9	1	$\frac{453.592\ 37/2.54^3}{13.595\ 088\ 9}$ = 2.036 022 34	$\frac{453.596\ 37/2.54^3}{0.998\ 278\ 282 \times 12}$ = 2.310 636 99	$\frac{453.592\ 37 \times 10}{13.595\ 088\ 9 \times 2.54^2}$ = 51.714 967 4	$\frac{980.665 \times 453.592\ 3}{2.54^2 \times 10^4}$ = 6.894 757 29
in. Hg (0°C)	$\frac{13.595\ 088\ 9 \times 2.54}{1\ 013\ 250/980.665}$ = 0.033 421 030 1	$\frac{13.595\ 088\ 9 \times 2.54}{10^6/980.665}$ = 0.033 863 858 8	$\frac{13.595\ 088\ 9 \times 2.54^3}{453.592\ 37}$ = 0.491 153 746	1	$\frac{13.595\ 088\ 9}{0.998\ 278\ 282 \times 12}$ = 1.134 878 01	25.4	$\frac{13.595\ 088\ 9 \times 2.54}{10^4/980.665}$ = 3.386 385 88
ft H_2O (20°C)	$\frac{0.998\ 278\ 282 \times 30.48}{1\ 013\ 250/980.665}$ = 0.029 449 006 6	$\frac{0.998\ 278\ 282 \times 30.48}{10^6/980.665}$ = 0.029 839 205 9	$\frac{0.998\ 278\ 282 \times 12}{453.592\ 37/2.54^3}$ = 0.432 781 092	$\frac{0.998\ 278\ 282 \times 12}{13.595\ 088\ 9}$ = 0.881 151 971	1	$\frac{9.982\ 782\ 82 \times 30.48}{13.595\ 088\ 9}$ = 22.381 260 1	$\frac{0.998\ 278\ 282 \times 30.4}{10^4/980.665}$ = 2.983 920 59
mm Hg (0°C)	$\frac{13.595\ 088\ 9}{10\ 132\ 500/980.665}$ = 0.001 315 788 59	$\frac{13.595\ 088\ 9}{10^7/980.665}$ = 0.001 333 222 79	$\frac{13.595\ 088\ 9 \times 2.54^2}{453.592\ 37 \times 10}$ = 0.019 336 761 7	$\frac{1.0}{25.4}$ = 0.039 370 078 7	$\frac{13.595\ 088\ 9}{9.982\ 782\ 82 \times 30.48}$ = 0.044 680 236 8	1	$\frac{13.595\ 088\ 9}{10^5/980.665}$ = 0.133 322 279
kPa	$\frac{1.0}{101.325}$ = 0.009 869 232 67	0.01	$\frac{2.54^2 \times 10^4}{980.665 \times 453.592\ 37}$ = 0.145 037 738	$\frac{10^4/980.665}{13.595\ 088\ 9 \times 2.54}$ = 0.295 300 074	$\frac{10^4/980.665}{0.998\ 278\ 282 \times 30.48}$ = 0.335 129 562	$\frac{10^5/980.665}{13.595\ 088\ 9}$ = 7.500 621 88	1

GENERAL NOTE: All values given in the rational fractions are exact except for the densities of water and mercury. The density of water (0.998 278 282 g/cm^3 at 20°C) is computed from the IFC Formulation. The density of mercury (13.595 088 9 g/cm^3 at 0°C) is taken from NBS Monograph 8, P3-4. For example, 1 bar = 1 bar × 0.986 923 267 atm/bar = 0.986 923 267 atm = (1/1.013 25) atm.

PERFORMANCE TEST CODES (PTC)

(continued)

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