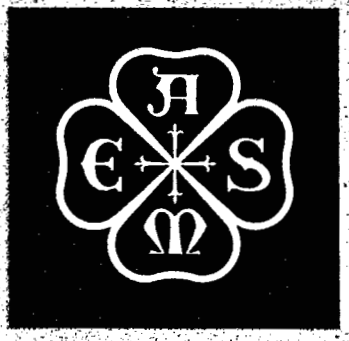
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PTC 31-1973

REAPPROVED '79

Ion Exchange Equipment



PERFORMANCE TEST CODES

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
United Engineering Center
345 East 47th Street New York, N.Y. 10017

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Ion Exchange Equipment

PERFORMANCE TEST CODES

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Foreword

The ASME Performance Test Codes Committee voted in December 1965 to establish a Test Code Committee for Demineralizers (PTC 31) and later approved as PTC 31 Committee's objective, the development of a Test Code which would define the procedures for the accurate testing of ion exchange equipment for the purpose of determining level of performance. The name of this Committee was changed at the request of PTC Committee No. 31 from Demineralizers to Ion Exchange Equipment on June 12, 1970.

Most steam generation cycles, either process application or utility power production, require the use of ion exchange equipment. Such equipment may be of simple construction, removing only hardness constituents from water, or may be relatively complex systems employing different types of ion exchange materials with a high degree of instrumentation and control logic. Additionally, ion exchange equipment is now being employed on virtually all types of nuclear steam generation cycles, processing water containing not only very high concentrations of impurities, but also treating liquids with impurity concentrations in the range of parts-per-billion to parts-per-trillion. Because performance of such process equipment directly influences the efficiency and output of steam generation cycles, a Committee was named by the American Society of Mechanical Engineers to draft a Performance Test Code for Ion Exchange Equipment. Members of this Committee were selected on the basis that ion exchange equipment manufacturers, users, and consultants as well as general interest groups were represented.

A draft of this Code was distributed in December 1972 for comment and criticism by industry and other interested individuals. The Code in final form was approved by the Performance Test Codes Committee on July 2, 1973 and approved and adopted by the Council of the Society by action of the Policy Board, Codes and Standards, on August 13, 1973.

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ON ION-EXCHANGE EQUIPMENT

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ASME PERFORMANCE TEST CODES
ION EXCHANGE EQUIPMENT

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SECTION 0, INTRODUCTION

0.1 This Code provides for the field testing of ion exchange equipment in order to determine level of performance. It is based on the use of accurate instrumentation and the best analytical and measurement procedures available. Only the relevant portion of this Code need apply to any individual case or test under consideration. In some cases the procedure is simple; however, for complex ion exchange systems or complex

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modes of system operation, the procedures and calculations of test results require more involved provisions for for testing.

0.2 This Code is recommended for use in conducting acceptance tests of ion exchange systems. If so used, any deviations from Code Procedure must be agreed upon in writing. In the absence of written agreement, the Code requirements shall be mandatory.

0.3 Before formulating the procedure for testing a specific ion exchange process or system, the Code on General Instructions PTC 1 – 1970 should be studied and followed in detail.

0.4 The Code on Definitions and Values (PTC 2 – 1971) defines certain technical terms and numerical constants. Unless otherwise specified in this Code, instrumentation should comply with the sections of Supplements on Instruments and Apparatus (PTC 19).

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ION EXCHANGE EQUIPMENT

SECTION 1, OBJECT AND SCOPE

1.1 This Code defines the procedures for the accurate testing of ion exchange equipment for the purpose of determining level of performance.

1.2 This Code includes the following types of ion exchange equipment, which are either used individually or in various combinations depending on process requirements.

Softener – Ion exchange equipment containing cation exchange resin used for the removal of hardness ions (calcium and magnesium), exchanging them for sodium ions.

Dealkalizer – The application of ion exchange equipment containing ion exchange resin to reduce alkalinity in waters. For example, anion resin in the chloride form may be utilized, exchanging bicarbonate, carbonate, nitrate and sulfate ions for chloride ions in this process.

Multi-Bed Systems – The combination of cation and anion exchangers, usually in series flow and sometimes in combination with mixed-bed exchangers, for the purpose of treating and processing water and/or dilute aqueous solutions.

Mixed-Bed Unit – The use of intimately mixed hydrogen-form cation resins and hydroxide-form anion resins in a single ion exchange vessel; this type of equipment usually provides the highest quality treated water.

Stratified-Bed Unit – The application of layers of weak-acid and strong-acid cation exchange resins, or weak-base and strong-base anion exchange resins in ion exchange vessels. This application is typically made to improve treatment efficiency.

Condensate Demineralizer – Ion exchange units applied to the removal of contaminants from steam condensates. Mixed-bed units are utilized for this application at much higher flow rates per square foot of resin bed surface than mixed-bed units employed for high solids water processing.

Condensate Sodium Ion-Exchanger – Ion exchange equipment containing cation exchange resin in the sodium form which is used for the removal of contaminants from steam condensates. Generally, this equipment is designed to operate at a much higher flow rate per square foot of resin bed surface than a typical softening ion-exchanger. Mixtures/blends of steam/process condensate and makeup water may also be processed by this equipment.

Organic-Trap – The application of selected ion exchange resins to remove large organic molecules from waters to be treated. This selection can be made in lieu of gravity separation and flocculation equipment, such as conventional clarifiers, to remove organics.

Mixed-Resin Unit (Special Ionic Form) – The use of intimately mixed cation and anion exchange resins in forms other than hydrogen and hydroxide. Such units are used in some applications for treatment of contaminated steam condensate. Other applications find use in treatment of nuclear primary coolant and nuclear waste management flows, performing soluble radionuclide removal as well as filtering capability for particulate removal.

1.3 This test Code applies to ion exchange equipment and systems that are utilized for:

(a) The conditioning of makeup, feedwater and/or steam condensate in a conventional fossil fuel cycle.

(b) The conditioning of makeup, feedwater and/or steam condensate in a nuclear cycle, primary coolant purification, core-bypass purification and use in waste management systems.

(c) The conditioning of process waters.

1.4 Ion exchange systems will typically consist of all equipment, including service, regeneration and resin storage vessels; and includes all piping, pumps, valves, controls, instrumentation and ion exchange resins.

1.5 Ion exchange systems are normally designed to regenerate ion exchange resin in either of two modes:

(a) In-place resin regeneration which is performed in the service vessel.

(b) External regeneration which is accomplished in specifically designed regeneration vessels which are part of the particular ion exchange system.

1.6 Ion exchange resins are normally regenerated with acids, alkalies, salts, or combinations of these materials to convert them to the exchange form desired. In some cases, such as specific nuclear applications, exchange resins may be supplied in a regenerated form ready for immediate use. These resins are normally disposed of after their service capacity has been utilized.

1.7 This Code applies to the performance of ion exchange equipment at design, minimum or maximum flow rates, depending on the purpose of the test, with regard to one or more of the following:

(a) Water quality, influent and effluent

(b) Pressure drop, flow and temperature

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(c) Operating ion exchange capacity
(d) Regeneration efficiency
(e) Resin volume and testing
(f) Backwash and rinse properties
(g) Regenerant purity and solution concentrations
(h) Resin transfer equipment

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ION EXCHANGE EQUIPMENT

SECTION 2, DESCRIPTION AND DEFINITION OF TERMS

2.1

Term	Definition
ACIDITY	An expression of the concentration of hydrogen ions present in a solution.
ALKALINITY	An expression of the total basic anions (hydroxyl groups) present in a solution. It also represents, particularly in water analysis, the bicarbonate, carbonate, and occasionally, the borate, silicate, and phosphate salts which will react with water to produce the hydroxyl groups.
ANION	A negatively charged ion, such as Cl^-, $SO_4^=$, NO_3^-, $CO_3^=$.
ANION EXCHANGE MATERIAL	An ion exchange material capable of the reversible exchange of negatively charged ions.
WEAK-BASE ANION MATERIAL	An ion exchange material containing the polyamine functional groups. It is highly ionized in the salt form and can operate only when pH is below 7: weakly ionized in the free base form, it has little, if any, salt splitting capacity and can remove the strong acids only.
INTERMEDIATE-BASE ANION MATERIAL	An ion exchange material containing a mixture of weakly basic and strongly basic groups. The properties of this resin are intermediate between the weak and strong base anion exchangers.
STRONG-BASE ANION MATERIAL	An ion exchange material containing the highly ionized quaternary ammonium functional group. It can remove both the highly dissociated strong acids and the weakly dissociated weak acids.
BREAKTHROUGH	The first appearance in the solution flowing from an ion exchange unit of unadsorbed ions similar to those which are depleting the activity of the resin bed. Breakthrough is an indication that regeneration of the resin is necessary.
CATION	A positively charged ion, such as Na^+, Ca^{++}, NH_4^+, Mg^{++}.
CATION EXCHANGE MATERIAL	An ion exchange material capable of the reversible exchange of positively charged ions.
WEAK-ACID CATION MATERIAL	An ion exchange material containing the weakly ionized carboxylic acid group, COOH, which has a

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Term	Description
	great affinity for the hydrogen ion. It removes only that part of the total cations that is equivalent in amount to the bicarbonate alkalinity.
INTERMEDIATE-ACID CATION MATERIAL	An ion exchange material containing a mixture of weakly acidic and strongly acidic groups. The properties of this resin are intermediate between the weak and strong acid cation exchangers.
STRONG ACID CATION MATERIAL	An ion exchange material containing the highly ionized sulfonic acid functional group (SO_3H). It can easily split salts converting them to acids.
CHANNELING	Cleavage and furrowing of the bed due to faulty design and/or operational procedures, in which the solution being treated follows the path of least resistance, runs through these furrows, and fails to contact active groups in other parts of the bed.
COLOR THROW	A term used to describe the phenomenon of processed effluent being colored more than the influent, generally caused by: Deterioration of ion exchange resin stored for prolonged periods at elevated temperatures. Deterioration of ion exchange resin due to repeated freezing and thawing. High content of iron in raw water. Microbial contamination of raw water.
CONDUCTIVITY	The electrical conductance of a solution is a general property, and is not specific for any particular ion. A number of analyses can be made, however, by means of a measurement of conductivity. In determining the quality of the effluent from certain ion exchange processes, it is an excellent method of assessing total salt content.
COUNTERFLOW	The direction of flow of the regenerant is upward while the exhaustion flow is downward. The terminology countercurrent is also used when indicating generally that the direction of the regenerant flow is opposite to the service run flow.
DEGASIFIER (FORCED-AIR)	Process equipment in demineralizer installations used to reduce or remove the free carbon dioxide from the water passed through it by contact between air and water.
DEGASIFIER (VACUUM)	Process equipment in demineralizer installations used

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ION EXCHANGE EQUIPMENT

Term	Description
	to reduce or remove the free carbon dioxide and air content from the water passed through it by subjecting the water to a vacuum.
DISTRIBUTOR (INLET)	A mechanical system generally located at the top of an exchanger through which the influent enters the vessel for processing. When located at the top of a vessel, it may also act as a collector of the backwash water which is discharged to waste. In addition, it serves to prevent disturbance of the top of the resin bed due to impingement by introducing the influent evenly over the surface of the resin bed.
DISTRIBUTOR (INTERFACE)	This is used primarily in mixed-bed demineralizers. As the name implies, it is located at the interface between the beds of cation and anion resins that is formed after the backwash classifies the two resins; it collects the spent alkali and acid that has passed through the cation and anion resin layers; it can be also used for distributing acid if it is to be passed downward through the cation resin bed and usually consists of a header and orificed laterals similar in design to the regenerant distributor. This type of distributor may also be used in other types of ion exchange equipment, as for example stratified-bed units.
DISTRIBUTOR (OUTLET)	A mechanical system generally located at the bottom of an exchanger through which the processed water (effluent) is collected from the resin bed on a uniform basis with respect to the entire cross section of the exchanger. When located at the bottom of a vessel, it may also serve as the distributor for resin backwash water and resin mixing air.
DISTRIBUTOR (REGENERANT)	A mechanical system through which the regenerant solution is introduced uniformly to the entire cross section of the exchanger for the maximum utilization of the regenerant solutions.
EFFICIENCY	The effectiveness of the operational performance of an ion exchanger. Efficiency in the adsorption of ions is expressed as the quantity of regenerant required to effect the removal of a specified unit weight of adsorbed material, e.g., pounds of acid per kilograin of salt removed.
EFFLUENT	A liquid, solid or gaseous product discharged or emerging from a process; in this particular Test Code, treated water discharged from an ion exchange system.

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Term	Description
ENDPOINT	That point of the service run where salt, acid or base leakage is sufficiently high to render the processed water unsuitable for a specific use. Determination of this value may be by conductivity, pH, or other measurements, and action required will generally be to remove the ion exchanger or ion exchange system from service at this point.
EXCHANGER	A pressure vessel containing ion exchange material through which water to be processed is passed. In some process applications, the exchanger may contain mixtures of cation and anion resins, or even mixtures of different cation or anion resins, such as stratified-bed units.
EXHAUSTION	The state in which the resin is no longer capable of useful ion exchange; the depletion of the exchanger's supply of available ions. The exhaustion point is determined arbitrarily in terms of: (a) a value in parts per million of ions in the effluent solution; (b) the reduction in quality of the effluent water determined by a conductivity bridge which measures the electrical resistance of the water, or any other suitable criteria such as leakage of radionuclides.
EXTERNAL REGENERATION	A procedure in which the ion exchange resins is sluiced or transferred (hydraulically, pneumatically, or by gravity) after exhaustion into another vessel wherein regeneration occurs.
FREEBOARD	The space provided above the resin bed in an ion exchange vessel to allow for expansion of the resin bed during backwashing.
FREE MINERAL ACIDITY (FMA)	The amount of acidity present in water when leakage is subtracted from TMA; FMA = TMA-leakage.
HARDNESS	The scale-forming and lather-inhibiting qualities which water, high in calcium and magnesium ions, possesses. Temporary hardness, caused by the presence of magnesium or calcium bicarbonate, is so called because it may be removed by boiling the water to convert the bicarbonates to the insoluble carbonates. Calcium sulfate, magnesium sulfate, and the chlorides of these two metals cause permanent hardness.
HARDNESS AS CALCIUM CARBONATE	The expression ascribed to the value obtained when the hardness-forming salts are calculated in terms of equivalent quantities of calcium carbonate: a convenient method of reducing all salts to a common basis for comparison.

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ION EXCHANGE EQUIPMENT

Term	Description
HYDROGEN CYCLE	The operation of a cation exchange cycle wherein the removal of specified cations from the influent water is accomplished by exchange with an equivalent amount of hydrogen ion from the exchange material.
INFLUENT	A liquid, solid, or gaseous material being introduced into a process; in this particular Test Code, untreated or partially treated water introduced for processing into an ion exchange system.
ION EXCHANGE	A reversible process by which ions are interchanged between a solid and a liquid with no substantial structural changes of the solid.
ION EXCHANGE CAPACITY (VOLUME BASIS)	The number of milliequivalents of exchangeable ions per milliliter of backwashed and settled ion-exchange material in its standard form; also expressed in terms of kilograins capacity/cubic foot of resin material.
ION EXCHANGE CAPACITY (WEIGHT BASIS)	The number of milliequivalents of exchangeable ions per dry gram of ion exchange material in its standard form.
ION EXCHANGE MATERIAL	An insoluble solid that has the ability to exchange reversibly certain ions in its structure or attached to its surface as functional groups with ions in a surrounding medium.
ION EXCHANGE RESIN	A synthetic organic ion exchange material, usually in spherical form. See definitions for anion exchange and cation exchange materials.
LEAKAGE	The amount of inlet salt or contaminant present in the processed, effluent water. Generally, a function of regenerant level of the ion exchange resin material, and also a function of the flow dynamics within the exchanger. May be expressed as a percentage of inlet concentration, or in dimensionless part-per-million (ppm) or part-per-billion (ppb) ion or salt terms.
MIXED-BED UNIT	The use of intimately mixed hydrogen-form cation resins and hydroxide-form anion resins in a single ion exchange vessel; this type of equipment usually provides the highest quality treated water.
MIXED-RESIN UNIT (SPECIAL IONIC FORM)	The use of intimately mixed cation and anion exchange resins in forms other than hydrogen and hydroxide. Such units are used in some applications for treatment of contaminated steam condensate. Other applications find use in treatment of nuclear primary coolant and nuclear waste management

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Term	Description
	flows, performing soluble radionuclide removal as well as filtering capability for particulate removal.
OPERATING CYCLE	An ion exchange process consisting of a regeneration phase and a service run.
pH	An expression of the acidity of a solution; the negative logarithm of the hydrogen ion concentration (pH 1 very acidic; pH 14, very basic; pH 7, neutral).
REGENERANT	The solution used to restore the activity of an ion exchanger. Acids are employed to restore a cation exchanger to its hydrogen form; brine solutions may be used to convert the cation exchanger to the sodium form. The anion exchanger may be rejuvenated by treatment with an alkaline solution.
REGENERATION	Restoration of the activity of an ion exchanger by replacing the ions adsorbed from the treated solution by ions that were absorbed initially on the resin.
REGENERATION (IN-PLACE)	A procedure in which the regenerant solutions are brought to the exhausted resin in the service vessels, and the regeneration is conducted there.
REGENERATION LEVEL	The weight of regenerant used per unit quantity of ion exchange material in a single regeneration. It is usually expressed in terms of pounds of regenerant (as 100 percent) per cubic foot of fully hydrated ion-exchange material, in a specific ionic form, measured after backwash and draining.
REGENERATION PHASE	A cycle consisting of a minimum of four steps; resin separation (backwashing) to clean the bed, introduction of the regenerant, a slow rinse or displacement to push the regenerant slowly through the bed and finally a fast rinse to remove all traces of regenerant from the resin.
RESIN FOULING	The phenomenon in which weak organic acids are absorbed by strong base anion resins and are not fully removed during regeneration; instead accumulate in, block the exchange sites, thus, diminishing the capacity of the resins. In addition, the effluent quality deteriorates resulting in leakage of the organic acids, greater leakage of total dissolved solids, equivalent higher conductivity and lower pH values. Larger rinse volumes requiring more time may also be incurred during the regeneration phase. Fouling of ion exchange resins may also be caused by impure grade of regenerants, high levels of influent turbidity during the

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Term	Description
	service run, and bacteria or iron in the water being processed (also during the service run).
RESIN SEPARATION (BACKWASH)	Separation of the anion resin from the cation resin by backwashing. Separation due to the difference in specific gravities of the anion resin and cation resin-normally the anion resin being lighter will float to the top of the cation resin. The term resin separation, or backwash, may also be applied to separation of resins in stratified-bed units.
RESIN STRAINER (RESIN TRAP)	Strainer used to prevent discharge of resins from the exchanger vessel into the feedwater system in the event of failure of the outlet distributor.
RINSE	That part of the regeneration phase of an ion exchange process in which water is passed through the bed of ion exchange material to remove the residual regenerant solution.
RINSE REQUIREMENT	Measure of the volume water used during regeneration before a resin can be put into service. Rinse requirements may be caused by impure grade of regenerants, hydraulic channeling, and contamination fouling and deterioration of the resin.
SERVICE RUN	That part of the operating cycle of an ion exchange process in which the influent is passed through a bed of the ion exchange material in order to exchange specific ions from the water for an equivalent amount of specific ions from the ion exchange material.
SODIUM CYCLE	The operation of a cation exchange cycle wherein the removal of specified cations from the influent water is accomplished by exchange with an equivalent amount of sodium ion from the exchange material.
THEORETICAL FREE MINERAL ACIDITY (TMA)	The free mineral acidity that would result from the conversion of all of the anions of strong acids in solution to their respective free acids.
UNITS OF MEASUREMENT	Units used to express concentrations, based on number, volume, or weight. *Milliequivalents per liter* — A unit of concentration obtained by dividing the number of grams per liter by the equivalent weight and multiplying by a thousand. (Equivalent weight is the weight in grams of a species which would react with one gram of hydrogen, seventeen grams of hydroxyl ion, or eight grams of oxygen.)

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Term	Description
	Milligrams per liter — The number of thousandths of a gram of a substance in one liter of water. To convert from moles to milligrams, multiply the number of moles by the atomic or molecular weight of the substance and multiply by one thousand.
	Moles per liter — The number of particles of a substance, expressed in moles, in one liter of water. One mole is 6.02×10^{23} particles. Moles per liter (molarity) is abbreviated M. Thus 10^{-7}M H^+ equals 6.02×10^{16} hydrogen ions per liter.
	Parts per million — Parts by weight of an ion or species in a given weight of solution. Thus 0.025 grams of calcium ion in one liter of water is 25 ppm, or 25 parts by weight in 1,000,000 parts by weight of solution.
	Percent (volume/volume) — The percent of total solution volume contributed by the dissolved species that has been added to the solution. Thus 40 percent (v/v) methanol is 40 ml of methanol in enough water to bring the solution to 100 ml.
	Percent (weight/weight) — The percent of total solution weight contributed by the dissolved species. Thus 10 percent KNO_3 (w/w) is 10 grams of KNO_3 in 90 grams of water. If not otherwise specified, percent implies percent by weight.
ZEOLITE	A group of complex hydrated aluminum silicates, either naturally occurring or synthetically manufactured with limited cation exchange properties.

2.2 Regeneration Efficiency

Regeneration efficiency, a measure of regenerant utilization, is commonly expressed either as pounds of regenerant per kilograin of exchange capacity as $CaCO_3/ft^3$, or as a percentage of what would be the stoichiometric quantity (one equivalent of regenerant per equivalent of ions exchanged).

$$\text{Operating exchange capacity (as Kgr } CaCO_3/ft^3) = \frac{\text{Gallons treated between regeneration} \times \text{Grains/gallon as } CaCO_3 \text{ of exchangeable ions*}}{ft^3 \text{ of resin} \times 1000}$$

$$\frac{\text{lb 100\% regenerant/ft}^3}{\text{Exchange capacity (Kgr } CaCO_3/ft^3)} = \text{Regeneration efficiency (lb 100\% regenerant/Kgr of exchange capacity)}$$

*Exchangeable ions are the ions being removed by the resin during operation of the system. In the case of water softening, calcium and magnesium would be the exchangeable ions.

Regeneration efficiency may also be expressed as follows:

$$\frac{\text{lb 100\% regenerant/ft}^3}{\text{Exchange capacity Kgr } CaCO_3/ft^3} \times \frac{F}{7} \times 100 = \text{Percent of stoichiometric}$$

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Factors (to express regenerant as $CaCO_3$)

Regenerant	F
HCl	1.37
H_2SO_4	1.02
NaOH	1.25
Na_2CO_3	0.944
NaCl	0.856
NH_4OH	1.43
NH_3 (anhydrous)	2.94

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SECTION 3, GUIDING PRINCIPLES

Advance Planning for Test

3.1 The parties to any test under this Code shall reach agreement as to the location of instrument connections, position of valves and arrangement of piping. When the interests of more than one party are involved, the parties to the test shall come to an agreement in writing and in advance of the test.

3.2 Items on which agreement shall be reached:

(a) Basis of guarantee conditions, test objective(s), duration of test, preliminary tests, methods of computing results, and expense of testing program.
(b) Need for, and extent of, equipment inspection before test and after test.
(c) Deviations, if any, from Test Code procedures.
(d) Personnel, including supervisor, conducting and observing test.
(e) That test objectives(s) can be realized under feasible test conditions with the existing installations.
(f) Whether apparatus is to be tested "as found" or after being conditioned for test. If the latter, the extent of the conditioning of the equipment required to make apparatus ready for test.
(g) Arrangement of test apparatus, instrumentation, and flow and cycle diagrams showing test points and data to be obtained. To avoid costly modifications, it should be noted that the instrumentation needed for a code test usually exceeds that normally provided for operation. The utilization of this Test Code should be discussed at such time that the required connections and valves may be provided for in the purchaser's piping and equipment design.
(h) Conditions to be held constant during test and the permissible deviations therefrom. Methods of extrapolating test data and results to the design conditions, if deviations greater than those previously agreed upon occur.
(i) Whether influent is to be treated, and if so, the treatment to be used.
(j) Analytical methods and limits of reporting accuracy for influent and effluent composition. Refer to Section 4, Instruments and Methods of Measurement.
(k) The choice of instruments and the probable limits of accuracy of the test results considering test procedures and probable accuracy of instruments selected, as given in the Supplements on Instruments and Apparatus.
(l) Procedures for inspecting the ion exchange resin and equipment to be sure overall system design, type of resins and resin volumes are as previously agreed.

General Description of Test Requirements

3.3 (a) Before conducting a test, all parties should have the right to examine the equipment to assure that it is in the condition agreed upon, to run a brief preliminary test to give assurance that the equipment is capable of reliable and continuous operation and to be satisfied that it is in condition to undergo Performance Testing.

(b) If the equipment is to be tested in the "as found" condition, the following should be recorded:
1. The length of time the equipment has been in service.
2. The number of operational cycles the equipment has completed.
3. Any unusual conditions that occurred prior to the test.

(c) All control devices and measuring instruments should be calibrated, and should be checked for proper installation and operation as indicated in Section 4, Instruments and Methods of Measurement.

Preliminary Tests

3.4 A preliminary test of at least one complete cycle after establishment of steady state conditions should be carried out to determine whether the equipment is operating satisfactorily and whether test procedures given herein, or agreed upon, are feasible. During this test, it should be ascertained that the equipment, controls, sample points and instrumentation are functioning to insure the recording of valid test data. Data obtained from this preliminary test should be used to determine if calibration procedures are acceptable. When preliminary inspection and test indicate that the limiting conditions for which the equipment was designed cannot

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be met, the parties to the test shall agree upon alternate conditions before the official test. The probable effect of these alternate conditions upon the performance of the apparatus shall also be agreed upon before the test unless it is agreed that one of the objects of the test will be to determine this effect.

Frequency of Observations

3.5 Test measurements necessary to obtain the data previously agreed upon shall be taken at sufficient intervals during the test periods to describe the performance of each step of the cycle. Frequency of readings shall be agreed upon in advance. Raw water quality and the influent composition to the various ion exchange resin units should be monitored during the testing. If any of these compositions are other than what was agreed upon earlier, as a result of a malfunctioning of mechanical equipment, corrective measures should be taken.

Duration of Test Runs

3.6 The tests shall be of a duration necessary to determine performance and to average out normal variations. It is recommended that the test consist of at least three cycles where makeup units are involved. In the case of polishing units, both high and low flows, where the service cycle is normally of a very long duration, the parties involved shall agree on the number of test cycles sufficient to establish performance.

General Description of Test Procedures

3.7 Ion exchange systems, as described in the introductory statements, require certain measurements during a performance/acceptance test. Although it is not possible to detail all measurements desired on specific ion-exchange systems, it is the intent of this part of the Test Code to indicate those test procedures which are generally required to establish system performance.

Differential pressure, flow, temperature measurements and resin volumes are primarily used for the determination of hydraulic characteristics of ion exchange systems. They may be utilized to determine overall system characteristics, or may be used to measure the performance of various subcomponents of the ion exchange system, as for example, individual differential pressure drop across a single tank in a multi-tank system. Similarly, flow measurements may be applied to determine backwash and rinse properties of individual subcomponents. Flow and time or volume measurements may also be used to verify chemical properties of ion exchange systems. Certain hydraulic properties, such as flow distribution within the ion exchange vessels, are not included in this part of the Test Code; chemical test methods as outlined in Par. 3.8 are more sensitive in the determination of such hydraulic characteristics than basic flow and differential pressure measurements.

(a) *Differential Pressure*

The measurement of pressure drop across the ion-exchange system, or subcomponents thereof, is normally accomplished by the use of line-mounted pressure gauges, dual-gauges, or transmitters of various mechanical, pneumatic or electronic designs, as described in Section 4, Instruments and Methods of Measurement.

The rate of particulate fouling of ion exchange resin beds as well as degradation, such as decrosslinking of resins, can be determined by the use of differential pressure measurements. Mechanical restrictions of flow would also be a source of an increased pressure differential. Effectiveness of resin bed backwash operations can also be determined by measuring pressure drop across the resin bed both before and after the backwash cycle.

(b) *Flow*

Evaluation of various flow streams can be accomplished by the use of suitable measurement devices as outlined in Section 4, Instruments and Methods of Measurement. Flow rate and volume measurement may be applied to determine backwash, regeneration, rinse and service parameters of ion exchange subcomponents. Backwash properties shall be observed to determine backwash effectiveness in the time prescribed. Backwash effluent shall be sampled periodically during the backwash cycle and observed for clarity and the presence of resin. Suitable types of flow meters can also be used to measure the total volume of water treated. The capability to measure ion exchange process flow rates and volume will establish, when coupled with suitable chemical analyses, overall ion exchange system performance.

(c) *Temperature*

Section 4, Instruments and Methods of Measurement refers to temperature measurement methods suitable for use in ion exchange equipment. Temperature measurements are important during the determination of proper backwash flow rates on ion exchange tanks so that optimum backwashing takes place. Additionally, regenerant solution and water sample temperatures must be measured during the determination of process efficiency, since abnormal regenerant temperatures will result in resin capacity deviations. Variations in sample temperatures will also influence conductivity, pH, and various colorimetric analyses. Samples should be temperature conditioned or, alternately, temperature compensation utilized.

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(d) *Resin Volume*

Resin volume measurements are made to determine if the ion exchange unit contains the proper quantity of resin. The chemical form of the resin at the time measurement is made is very important and the equipment manufacturer's manual should be consulted on this point. Also, some resins will undergo a certain amount of irreversible expansion during the first operational cycle. This property is usually associated with certain weak base and weak acid ion exchange resins. In such cases, it is desirable to place the unit through several operational cycles before the resin volume measurement is made.

The following method for resin volume measurement is one of many that can be utilized for this purpose; in any method, due consideration must be given to vessel head volume and internal distributor displacement volume.

Backwash unit so that resin bed is expanded at least 50 percent, for a 10-minute period.

With the vessel at atmospheric pressure at a flow rate not to exceed 1 gpm/sq ft drain the water level in the unit down to where it is six inches above the resin. Measurement of the resin bed depth should be made, being careful not to jar the vessel or disturb the resin bed.

With the measurement of resin bed depth, knowing the inside diameter of the unit, the resin volume can be calculated. Conversely, freeboard volume may be calculated and this value subtracted from the entire tank volume, which will then give the gross resin volume. Subtraction of distributor displacement volume (available from the equipment manufacturer) then completes the calculation to produce net resin volume.

3.8 Chemical measurements are primarily utilized for the determination of chemical properties of ion exchange equipment and systems.

Influent and Effluent Quality
Regenerant Solution Concentration and Purity

These measurements primarily determine the chemical properties of ion exchange systems. Although other parameters could be used, such as spent-regenerant analyses, the performance of the ion exchange system can be adequately established by the test categories listed. They may be utilized to determine overall system characteristics, or may be used to measure performance of various subcomponents of the ion exchange system, as for example, cation resin bed effluent and degasifier effluent quality.

Although the properties of ion exchange resin are not listed above, the test procedures for determining these properties are fully covered in Section 4, Instruments and Methods of Measurement.

(a) *Influent and Effluent Quality*

Par. 3.9 lists common impurities which may require measurement during acceptance/performance testing of ion exchange systems. The analysis of various constituents will vary from system to system, and Par. 3.10 illustrates the general measurements required for different classes of ion exchange facilities. (For analytical procedures, refer to PTC 19.11 (1970) or appropriate ASTM methods,)

In addition to the dissolved salts contained in waters to be treated by ion exchange, non-ionic impurities may also be present and their presence should at least be known. Since influent water to ion exchange systems must be as free as possible of fouling constituents, pretreatment equipment may precede ion exchange systems. Such pretreatment facilities during their normal operation may significantly alter the composition of the water to be treated by the following ion exchange equipment. Since the design of ion exchange facilities may be based on the processing of pretreated water, performance measurements of ion exchange equipment must be based on adequate analyses of such waters.

(b) *Regenerant Solution Concentration and Purity*

Regeneration solution concentrations should be determined to be certain that they are the concentrations required for application at the ion exchange bed, and also to verify concentration calculated from the flow rates of concentrated regenerant and dilution water. Concentrations may be determined by measurement for specific gravity, conductivity or by chemical analysis.

In the operation of ion exchange equipment, one of the most important factors in the maintenance of exchange capacity is the quality of the regenerant chemical used in the regeneration step. Although chemically pure (CP) chemicals are not required for regeneration of ion exchange equipment, it has been found that certain contaminants in regenerant chemicals collect on the ion exchange resins and eventually cause difficulty in operation.

Technical grade chemicals, free of oils, suspended solids, and organic materials, are suitable for regeneration of cation exchange resins.

Industrial water softeners generally use rock salt for economy. Hydrogen exchangers are generally regenerated with either sulfuric or hydrochloric acids. Technical grade 66° Be′ sulfuric acid, free of suspended matter, and light in color may be used. Occasionally, technical grade 60° Be′ sulfuric acid may be available for use as a regenerant, and may be employed if of suitable purity (see Appendix I).

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Hydrochloric or muriatic acid may be technical grade, of a minimum of 30 percent HCl by weight (18°Be′). The hydrochloric acid should not contain excessive iron or organic materials. By-product acid should be used with caution since certain impurities can result in loss of exchange capacity. If the hydrochloric acid is a by-product obtained from hydrolysis of chlorinated organic chemicals, it should not be used if the solution passing through the cation exchanger is to be used for consumption and food processing.

Anion exchange resins are generally regenerated with sodium hydroxide (NaOH). Weak base anion exchangers are most economically regenerated with technical grade flake sodium hydroxide, 76 percent Na_2O, purified anhydrous. Strong base anion exchangers are best regenerated with nylon or rayon grade purified sodium hydroxide, 76 percent Na_2O. This grade of caustic is low in iron, silica, chlorides and chlorates. This eliminates fouling of the strong base anion exchangers. If caustic is purchased in the liquid form as a 50 percent solution, the same grades may be purchased as mentioned above. The chlorate ions present in caustic soda solution cause loss of exchange capacity when adsorbed on an anion exchange resin. If it is necessary to use caustic which has a very high chlorate ($NaClO_3$) content, satisfactory day-to-day performance will be obtained; resin operating life, however, can be expected to be less than that which would be obtained using a grade of caustic which contained no more than the maximum specified amount of chlorate as indicated in Appendix I. Weak base anion exchangers may also be regenerated with soda ash or ammonium hydroxide: technical grade powdered soda ash should be purchased; ammonium hydroxide may be purchased in 12.5 gallon carboys as a 28 percent NH_3 solution. Anhydrous as well as aqueous ammonia can be used.

Recommended Regenerant Quality for various types of ion exchange resins is to be found in Appendix I.

Common Impurities Which May Require Measurement During Ion Exchange System Performance Testing

3.9

Dissolved	Undissolved	Gaseous
Cations	Bacteria	Ammonia
Aluminum	Color	Carbon Dioxide
Ammonium	Colloidal materials	Chlorine
Calcium } total hardness	Condensate corrosion products	Hydrogen sulfide
Magnesium } total hardness	Organic materials	Oxygen
Copper	Suspended materials, such as turbidity, silt, and dirt.	
Hydrogen (pH)		
Iron		
Manganese		
Potassium		
Sodium		
Anions		
Alkalinity		
Bicarbonate		
Carbonate		
Chloride		
Fluoride		
Hydroxide		
Nitrate		
Phosphate		
Silica		
Sulfate		
Sulfide		
Sulfite		
Total dissolved solids – conductivity		

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Note

1. Hardness may be measured directly in terms of $CaCO_3$, or may be calculated from Ca and Mg ion concentrations.
2. Alkalinity may be measured directly in terms of $CaCO_3$, or may be calculated from bicarbonate, carbonate and hydroxide ion concentrations.

Chemical Measurements During Ion Exchange Systems Performance Testing

3.10

Ion Exchange System	Typical Measurements	
	Influent	**Effluent**
Sodium ion exchange	Calcium, Magnesium (total hardness*) Chlorine* Turbidity* Total cations* Iron* Manganese* Oxygen[1]	Calcium, Magnesium (total hardness*)
Sodium ion exchange plus hydrogen ion exchange (Blended effluents)	Total hardness* Chlorine Alkalinity* Turbidity* Total cations* Theoretical mineral acidity* Iron* Manganese* pH	Total hardness* Alkalinity* pH
Sodium ion exchange plus chloride anion ion exchange	Total hardness* Chlorine* Alkalinity* Color Organic Materials Total cation Turbidity* Theoretical mineral acidity Chloride Nitrate* Sulfate	Total hardness* Alkalinity* pH
Hydrogen ion exchange	Total hardness*	Total hardness*

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ION EXCHANGE EQUIPMENT

Ion Exchange System	Typical Measurements	
	Influent	Effluent
(Weakly and strongly acidic type cation exchange resins)	Sodium* Color Chlorine* Turbidity*	Sodium* pH Chloride, Nitrate, Sulfate } Free mineral acidity (FMA) Conductivity CO
Demineralization with weak base anion ion exchanger	Total hardness* Sodium* Alkalinity* Color Organic Materials* Theoretical mineral acidity* Chloride Sulfate Nitrate* Turbidity* Phosphate pH	Total hardness* Sodium* Alkalinity Conductivity* pH*
Demineralization with strong base anion ion exchanger	Total hardness* Sodium Alkalinity* Color Organic Materials* Chlorine* Silica* Conductivity Theoretical mineral acidity Chloride* Nitrate* Sulfate* Turbidity* CO_2 Phosphate pH	Total hardness* Sodium* Alkalinity Silica* Conductivity Chloride Nitrate Sulfate pH*
Condensate sodium ion exchanger	Total hardness* Conductivity Iron* Oxygen[1] Suspended solids* Amines* Ammonia Total cations	Total hardness* Iron* Suspended solids*[2] Conductivity*

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Ion Exchange System	Typical Measurements	
	Influent	Effluent
Condensate demineralization (Applies to hydrogen-hydroxide and ammonium-hydroxide mixed beds)	Ammonia* Sodium* Soluble iron* Suspended iron* Copper* Oxygen Chloride Cation conductivity* Specific conductivity Silica Hydrazine* pH	Ammonia* Sodium* Iron* Copper* Chloride Cation conductivity* Specific conductivity* Silica Suspended solids* pH*
Nuclear coolant ion exchange (Applies to lithium hydroxide, ammonium hydroxide, potassium hydroxide, and hydrogen hydroxide-mixed resin units, and those in which the cation resin contains one of these metals and the anion is in the borate form)	Activity level*	Activity level*

*Major importance for the type of ion exchange system listed:

[1] Also major importance if system operating above 170°F.

[2] Analytical procedure given in Section 4, Instruments and Methods of Measurement.

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SECTION 4, INSTRUMENTS AND METHODS OF MEASUREMENT

4.1 This Code presents the mandatory requirements for instruments, methods and precautions of measurement which shall be employed. The Performance Test Code Supplements on Instruments and Apparatus provide general and authoritative information concerning instruments and their use, and should be consulted if sufficient information is not included in this Code.

By mutual agreement of the parties to the test, instrument devices and systems such as those using electronic devices or mass-flow techniques may be used as alternative to the mandatory Code instrument requirements, provided that the application of such devices and systems has demonstrated accuracy equivalent to that required by this Code.

Reference is made herein to the latest revision of the ASME Performance Test Code, PTC-19, Supplements on Instruments and Apparatus:

Part 1, General Considerations
Part 2, Pressure Measurements
Part 3, Temperature Measurement
Part 5, Measurement of Quantity of Materials
Part 16, Density Determinations

Mechanical Measurements

4.2 Measurements may be made to determine flow rates for backwash, regenerant introduction, rinse, service, and as part of the pressure loss test. Normally, a flow meter is provided in the inlet lines to an ion exchange unit which may be used for these measurements. If flow meters are not available for test purposes, flow rates may be determined in small ion exchange systems by diverting the flow from the ion exchange unit to a vessel of suitable size for either weight or volume measurement subject to agreement of the parties of the test. If weight determinations are to be used, it will also be necessary to determine specific gravity of the fluid being measured and this correction applied to obtain true volume flow rates.

4.3 For determination of concentrated regenerant flow rates and determination of total volume of concentrated regenerant used, the regenerant should be placed in a calibrated volume tank and the rate of drawdown determined per increment of time as the regenerant is fed into the ion exchange unit. Alternately, regenerant pumping rates (volume) and time with chemical analyses may be employed.

4.4 Temperature measurements will be required to determine correct backwash rate for each ion exchange unit to determine that the resin is being operated within specified temperature limitations; to determine that regenerant temperature is within the specified range; and to establish need for correction factors for pH, conductivity, or other tests that are temperature sensitive.

If temperature-measuring instruments are provided at suitable locations in the system, they may be used. All temperature-measuring devices may be tested and correction factors determined by methods given in PTC 19.3 (1961) if the parties to the test deem it necessary. If any additional instruments are required, it is preferred that they be installed in thermometer wells installed in the pipelines where temperature measurement is required. In systems operating at less than 200°F, temperatures may be measured at outlet points by immersing the sensing element in a container and allowing the water to overflow from this container into another surrounding container from which it may finally flow to waste.

4.5 Measurement of pressure loss in an ion exchange system may be made (1) to determine physical or chemical condition of ion exchange resin bed; (2) to determine condition of entire unit; (3) to determine overall condition of an entire train of two or more ion exchange units operating in series; or (4) effectiveness of backwash. Prior to testing, it will be necessary to agree on the flow rate or flow rates at which the test will be made, and to establish whether the test will be made after backwashing or immediately after regenerating the unit. Suitable pressure-sensing connections are to be made available. For the preferred method of sensing connections, refer to the latest revision of PTC 19.2.

Pressure loss of the magnitude expected across a single unit or train of multiple units may be measured by a diaphragm or bellows-type differential gauge or by a pair of matched, calibrated Bourdon tube-type pressure gauges. If a pair of gauges is used, they should be mounted at the same elevation in order to avoid the necessity of correction for different static head and to allow for simultaneous reading of inlet and outlet pressures. Ranges of the pressure gauges should be appropriately selected. Gauges should be calibrated with a deadweight tester prior to the test period.

4.6 Pressure loss measurement may be made across the resin bed to indicate the rate of particulate fouling, resin degradation, or of backwash effectiveness. If the purpose of the test is to determine particulate fouling, crud buildup, or backwash effectiveness, pressure loss tests should be made immediately before and after backwash, using the same flow rates for each pressure loss

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test. For determination of resin degration, the resin should be regenerated in the normal manner and the pressure loss test made just after rinse is completed, prior to returning the unit to service.

4.7 For pressure loss tests across the bed only, it is necessary to have pressure connections available in the ion exchange vessel above the resin bed and at, or near, the bottom of the bed. On units equipped with an air vent in the top head of the vessel, the pressure above the bed may obtained from this connection. Pressure at the bottom of the bed will require a suitable probe that can be inserted into the bed as near as possible to the bottom of the resin layer. If the vessel has a resin removal opening in the side near the bottom of the bed, this opening can be used for insertion of a sensing probe. An alternate method is to insert the probe through the air vent connection until the probe head is at the bottom of the resin bed. A precise measurement of pressure loss through the resin bed only cannot be made by using pressure sensing points in the inlet and outlet piping, since this would also include unknown losses across the inlet and outlet headers and some external piping.

For greatest accuracy of reading small changes in pressure, use of a fluid-filled manometer is preferable. The manometer is considered to be a primary standard for pressure measurement when made of uniform, large-bore tubing. As alternates, Class AA bellows, diaphragm, or Bourdon tube-type gauges may be used. If these gauges are to be used, they should be calibrated prior to the test by means of a deadweight tester in accordance with the latest revision of PTC 19.2 and the calibration chart for each made a part of the test records.

Chemical Measurements

4.8 The necessary instruments and mandatory rules for making measurements are prescribed herein. Specific references are made to ASME Power Test Codes, to the Supplements on Instruments and Apparatus, PTC 19.11 (1970) and to other publications describing detailed methods and apparatus which shall be employed in testing ion exchange equipment under the Code.

Sampling of Water from Influent and Effluent of Ion Exchange Equipment

4.9 Sampling of water shall be in accordance with the method outlined in ASTM 510-68, Standard Methods of Sampling Industrial Water and Section 2.2 ASME PTC 19.11 (1970). These methods cover the sampling of industrial water and include:

- Sampling for chemical or physical tests
- Sampling for biological tests
- Sampling for radioactivity determinations
- Sampling for continual analysis

Normal variations in processes and in equipment from plant to plant preclude the possibility of specifying methods of sampling that are applicable in all cases. However, definite principles have been established which are applicable in general and in most specific cases. Where modifications or changes in these procedures may be necessary under specific circumstances, they may be made by mutual agreement of the parties concerned.

Results in all cases shall be reported in accordance with ASTM D596, Standard Method of Reporting Results of Analysis of Water.

Reference is made to ASME Performance Test Codes, Instruments and Apparatus Supplement, Water and Steam in the Power Cycle (Purity and Quality, Leak Detection and Measurement), (PTC 19.11 – 1970) and to other publications describing detailed methods and apparatus which shall be employed in testing under this Code. For a more complete listing of constituents to be measured with respect to particular ion exchange systems, refer to Pars. 3.9 and 3.10, Guiding Principles.

Chemical and biological tests for measuring ion-exchanger influent and effluent constituents may be found in ASME PTC 19.11 and in American Society for Testing Materials (ASTM) Standards, Part 23, Water; Atmospheric Analysis. A list of suggested ASTM methods is detailed in Appendix II.

4.10 Field Sampling of Ion Exchange Materials

Field sampling of ion exchange materials shall be done in accordance with the method outlined in ASTM D-2687-72, Sampling of Particulate Ion Exchange Materials. The method covers sampling of ion exchange materials as received from the manufacturer in the original shipping container and prior to any resin-conditioning procedure. The sampling of ion exchange material from a fixed bed can be performed, using the general principles outlined in the above ASTM method and suitable sampling equipment agreed upon by all parties involved.

4.11 Field Measurement of Resin Volume

Refer to Par. 3.7, item (d), Section 3, Guiding Principles.

4.12 Analysis of Ion Exchange Materials

(a) The analytical methods generally employed to determine physical and chemical properties of ion exchange resins are primarily intended for laboratory use; that is, they are not easily adapted or modified to field applications. The following tests will adequately

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determine acceptability (or rejection) of resins:

Moisture
Density
Percent whole beads
Strong acid exchange capacity
Strong base exchange capacity
Weak acid exchange capacity
Weak base exchange capacity
Sieve analysis
Column capacity

These tests are fully described in ASTM D-1782-72 and ASTM D-2187-72, as well as ASTM D-3087-72

(b) The analysis of ion exchange resins shall be done in accordance with the methods outlined in ASTM D-1782-72, Tests for operating performance of particulate cation exchange materials.

The methods cover:
Pretreatment
Water retention capacity
Backwashed and settled density
Particle size distribution
Salt-splitting capacity of cation exchange resins
Total capacity of cation exchange resins

Depending on the type of ion exchange material and its specific application, it may be necessary to measure other chemical or physical properties, such as:

Total and salt-splitting capacity of strong base anion exchange resins
Total capacity of chelating resins
Total capacity of weak and intermediate acid cation ion exchange resins
Total capacity of weak-base anion exchange resins
Microscopic examination
Thermal stability
Physical attrition
Osmotic shock

In these cases, the analyses can be performed using the general principles outlined in the above ASTM methods and methods agreed upon by all parties involved.

The ion exchange resin should be analyzed prior to operation. This will provide a record of the properties of the as-received unused material and serve for comparison purposes. The analyses to be done should be agreed upon by the parties concerned.

(c) Status of ASTM Publications as of 1973. At the present time, the ASTM has completed and published the following test procedures for ion exchange resins.

ASTM D-1782-72
This publication covers column testing techniques for cation exchange resins.

ASTM D-2187-72
Implementation of this analytical method allows the determination of physical and chemical properties of particulate ion exchange resins.

ASTM D-2687-72
This method covers procedures for obtaining representative samples of ion exchange resins.

ASTM-D3087-72
This analytical method will assist in determining the operating performance of anion exchange materials.

4.13 Sampling for Suspended Solids

Crud or suspended solids is of primary interest with respect to condensate demineralizers, while ion exchange capacity is more applicable to makeup demineralizers. Although a wall (flush) sample tap can give representative samples in many situations, the preferred probe design (as described in ASTM 1066) is recommended for all applications where particulates in the stream are of interest. As noted in ASTM 1066 Section 5.4, isokinetic sampling should be employed to obtain a representative sample in any two-phase system, which includes steam/water mixtures as well as water/particulates.

Turbulent flow (Reynolds No. >4000) should be maintained over the entire length of the sampling line including the sample cooler, if any. To maintain as high a degree of turbulence as possible at a given sample flow rate, the sample cooler, if required, should be located as near as possible to the sample line termination. Minimum flow rates required for turbulent flow can be easily calculated, and are a function of line size (ID) and sample temperature. Within the requirements to maintain turbulent sample line flow and isokinetic sample flow rate through the sample probe, sample line size can be set by other system design conditions.

All sample lines should be flushed thoroughly prior to sampling. The valves should be then returned to a "set-point" position with respect to sample flow requirements. All sample valves should be of the type designed with a minimum of internal pressure drop or flow disturbance. The same parameters concerning sampling for suspended solids should be used at the influent and effluent of the ion exchange equipment or system.

(a) Membrane comparison charts are a rapid means for estimation of total iron present in a particulate form (crud) or mixture. The color produced depends not only on the concentration, but also on the particle size distribution, morphology, and composition of the suspended solids. Reference is made here to Appendix III of this Test Code which details methods of preparing membrane comparison charts.

(b) The capacity of ion exchange resin for the removal

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of crud will depend on the concentration of the influent suspended material. In general, a greater capacity is obtained at higher influent concentrations (0.5 to 2.0 ppm) than at lower influent concentrations (<0.1 ppm). The capacity will depend on the composition of the crud. In general, a higher capacity is obtained for magnetite than hydrated iron oxides. Other parameters affecting this are the number of regenerations, regeneration level, backwash flow rate, and the operational flow rate, In general, higher flow rates (>25 gpm/ft^2) produce higher capacities (or removal efficiency) for crud than low flow rates (<25 gpm/ft^2).

4.14 Ion Exchange Capacity

The ionic form of the operating unit and the type and concentration of the chemical additives present in the influent must be considered.

(a) The influent and effluent ammonia concentration must be determined for a unit operating in the ammonia cycle and using ammonia treatment. Cation conductivity measurements, however, may be useful in determining service characteristics; additionally, specific ion electrodes may be utilized in the determination of certain ions which require measurement.

(b) Dissolved solids determination by electrical conductivity alone cannot be used in all cases to determine operating ion exchange capacity. In some cases, the dissolved solids must be calculated from the complete water analysis. For example, weakly ionized dissolved solids such as silica and boric acid contribute little to electrical conductivity. The amount present, as found by separate determination, should be added to the dissolved solids calculated from conductivity to obtain the total dissolved solids.

(c) In other cases, measurement of electrical conductivity may not be practical for determining operating ion exchange capacity. These would be instances where the electrical conductivity does not change significantly, regardless of the concentration of dissolved solids. An example would be the determination of the lithium or ammonium capacity of a reactor coolant purification ion exchanger operating in the hydrogen-borate form and a high concentration of boric acid present in the coolant. Another example would be the determination of the operating capacity of a reactor demineralizer for "trace" concentrations of radioactive ions. In these cases, the determination of capacity should be made by using the appropriate analytical procedure.

(d) The testing of ion exchange resin for removal of trace (parts-per-trillion, parts-per-billion) quantities of soluble radionuclides should reflect the fact that concentration is the primary factor to be considered. For example, concentrated test solutions will indicate higher capacities than will the operational case. The calculation necessary to arrive at the value of the regeneration efficiency should be done in accordance with Section 2.2, Description and Definition of Terms.

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SECTION 5, COMPUTATION OF RESULTS

5.1 Performance of various types of ion exchange equipment and systems is computed as described in the following parts. Since it is unlikely that all operating conditions can be maintained exactly at the specified values, it will be necessary to correct test performance for the effect of such deviations.

(a) *Mechanical Measurements*

Flow rates, differential pressure and temperature measurements shall be computed from the readings in accordance with the directions given in the necessary Sections and parts of this Code, which refer therein to the appropriate ASME Codes which have been selected for particular measurements.

(b) *Chemical Measurements*

Analytical measurements shall be performed on necessary water samples for recommended constituents for the particular ion exchange equipment or system under test, see Par. 3.10, Section 3, Guiding Principles.

The Instruments and Methods of Measurement Section of this Test Code refers to the appropriate ASTM test procedure applicable for selected constituents to be measured concerning influent and effluent analysis as well as ion exchange materials analysis.

5.2 It is desirable that a performance bench mark be established immediately after the ion exchange equipment or system is first placed in service. Should the Code Test be delayed, there should be reasonable assurance that the ion exchange equipment or system has not been damaged or become fouled with various materials during the intervening period of operation.

5.3 It is recommended that calculations and analytical programs to obtain preliminary test results be carried out simultaneously with the conducting of the tests. Such a procedure provides an opportunity for early examination of the test data and the discovery of any observer errors, instrument errors or failures, and other causes for repeat tests. Shortly after the conclusion of this initial test series, it should be reasonably clear whether the test results are consistent and acceptable, or whether further preliminary testing is required.

5.4 The specified performance and the results of tests covering a series of runs and measurements may be expressed as a single value with respect to the removal of individual constituents within the process water being treated; single values for ion exchange capacity can be calculated also with respect to individual constituents. For calculation of ion exchange capacity, refer to part 2.2, Section 2, Description and Definition of Terms.

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SECTION 6, REPORT OF TESTS

6.1 The following tabulation is a guide for reporting the results of tests. Depending on the type and size of ion exchange system or equipment to be tested, certain readings may be omitted and others added. Since standardization of tests results is of great convenience to those who use reports, it is recommended that the table be used with as few modifications as possible. The test report should only include that data which is of significance in apparaising the performance of the equipment or system. Any other data used to support calculations, results, etc., should be included in other sections of the report, if desired.

(a) **GENERAL INFORMATION**

1. Date of test
2. Location of equipment
3. Owner
4. Source of influent water (well, river, process, etc.)
5. Building
6. Method of pretreatment
7. Test conducted by
8. General objective of test

(b) **DESCRIPTION OF EQUIPMENT**

1. Basic type of ion exchange system
2. Builder's drawing numbers
3. Number, size, and arrangement of vessels
4. Size and arrangement of external piping
5. Volume, specific type and bed depth of resin in each vessel
6. Description and location of flow measuring devices for water and regenerant solutions
7. Description and location of water pressure gauges
8. Description and arrangement of special test apparatus, including location of sampling points
9. Capacity and guarantees:
   - Flow rate, gpm, (min, max, avg, peak)
   - Exchange capacity, kilograins
   - Throughput per cycle, gallons
   - Pressure drop, psi
   - Influent design analysis
   - Effluent water quality guarantee
   - End points (measured in terms of conductivity or other applicable criteria)
10. Description of Builder's Standard Regeneration Procedure, including flow rates, time, amount and type of regenerants

(c) **DESCRIPTION OF TEST**

1. Operating history prior to test
2. Description of procedures used in preconditioning equipment specifically for the test
3. General description of test procedures
4. Corrections for deviations from specified test conditions
5. Description of test methods used other than those originally specified

(d) **OBSERVATIONS (mean observations derived from log sheets)**

1. Influent water:
   - Source
   - Pressure
   - Temperature
   - Quality
2. Effluent water:
   - Pressure
   - Quality
3. Flow rate
4. Volume of resin in each vessel
5. Amount of regenerant used per regeneration cycle and use concentrations
6. Rinse volumes

(e) **RESULTS**

1. Throughput per cycle
2. Pressure drop at design flow rate
3. Corrections to specified test conditions
4. Calculated regeneration efficiency, refer to Section 2, Descriptions and Definition of Terms

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(f) **CONCLUSIONS**

1. Points of acceptance
2. Points of deficiency
3. Remarks

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APPENDIX I
REGENERANT PURITY REQUIREMENTS FOR ION EXCHANGE MATERIALS

(a) *Regenerants for Cation Exchange Resins Used in the Hydrogen Form*

HYDROCHLORIC (MURIATIC ACID)

Grade – Muriatic acid, technical (HCl)
Color – White to light yellow
Concentration – Minimum (18°Be′)
28 percent HCl
Iron (Fe) – 40 ppm maximum

Acid should be free of turbidity and sediment; acid containing inhibitors should be used.

SULFURIC ACID

Grade – Sulfuric acid, technical (H_2SO_4)
Color – Water white to light brown
Concentration – Minimum (66°Be′) –
93.2 percent H_2SO_4

(Note – An equivalent amount of 60°Be′ acid may be used)

Iron (Fe) – 40 ppm maximum

Acid should be free of turbidity and sediment; acid containing inhibitors should not be used.

(b) *Regenerants for Cation Exchange Resins Used in the Sodium Form*

SODIUM CHLORIDE

In general, salt (sodium chloride) used for softeners should be suitable for the type of equipment or system employed as to:

1. Freedom from undesirable soluble impurities
2. Low content of insolubles which will not clog injectors and distributors or erode regenerant piping
3. Negligible mushing or caking in the brine tank

The following are several grades of salt available for regeneration purposes:

TYPICAL ANALYSIS (AVERAGE)	SOLAR EVAPORATED SALT (KILN DRIED)	EVAPORATED SALT	ROCK SALT
NaCl	99.5%	99.7%	98.8%
Water insoluble impurities	< 0.1%	< 0.01	< 2%
Moisture	< 0.3%	< 0.1%	< 0.2%
Ca	< 0.1%	< 0.1%	< 0.4%
Mg	< 0.03%	< 0.01%	< 0.1%
SO_4	< 0.2%	< 0.3%	< 0.9%
Alk	Nil	Nil	< 0.01%
Fe	< 0.01%	< 0.01%	< 0.01%

(c) *Regenerants for Anion Exchange Resins*

Sodium Hydroxide
Liquid Caustic Soda

50 percent sodium hydroxide (purified or mercury cell grade)

TYPICAL ANALYSIS	AVERAGE
NaOH	51%
Na_2CO_3	200 ppm
NaCl	300 ppm (on dry basis)
$NaClO_3$	500 ppm
SiO_2	10 ppm
Fe_2O_3	10 ppm
Al_2O_3	10 ppm
CaO	20 ppm
MgO	5 ppm

Sodium Hydroxide
Caustic Soda

76.2 percent Na_2O equivalent (purified or mercury cell grade)

TYPICAL ANALYSIS	AVERAGE
Na_2O	76.2%
NaOH	97.7%
NaCl	300 ppm
$NaClO_3$	1000 ppm
Fe_2O_3	20 ppm
Al_2O_3	20 ppm
CaO	40 ppm
MgO	10 ppm
Color	White

Soda Ash – Sodium Carbonate

Grade – Soda ash, technical, dense (Na_2CO_3)

TYPICAL ANALYSIS	AVERAGE
Na_2O	58.26%
Na_2CO_3	99.6%
Fe_2O_3	20 ppm
Water insolubles	100 ppm
Color	White

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(d) *Regenerant for Cation Resin in the Ammonia Form, or Certain Weak Base Anion Resins*

Ammonium Hydroxide

PHYSICAL PROPERTIES

Appearance – clear water – white liquid
Specific gravity of 29.4 percent NH_3 60/60°F = 0.8974
(26° Baume)

CHEMICAL PROPERTIES

Hydrogen sulfide – None
Pyridine – Less than 1 gram per liter
Organic matter – 50 ppm maximum

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APPENDIX II

ASTM Standards

D 510-68	Methods of Sampling Industrial water
D 511-52 (1972)	Test for Calcium and Magnesium Ion in Industrial Water
D 512-67	Tests for Chloride Ion in Industrial Water and Industrial Waste Water
D 513-71	Test for Carbon Dioxide and Bicarbonate and Carbonate Ions in Water
D 514-67	Test for Hydroxide Ion in Industrial Water and Waste Water
D 515-72	Tests for Phosphorus in Industrial Water
D 516-68	Tests for Sulfate Ion in Industrial Water and Industrial Waste Water
D 596-69	Method of Reporting Results of Analysis of Water
D 857-69	Tests for Aluminum in Water
D 858-65 (1971)	Test for Manganese in Water
D 859-68	Tests for Silica in Industrial Water and Industrial Waste Water
D 888-66 (1971)	Tests for Dissolved Oxygen in Industrial Water
D 992-71	Test for Nitrate Ion in Water
D 1067-70	Tests for Acidity or Alkalinity of Water
D1068-68	Tests for Iron in Industrial Water and Industrial Waste Water
D 1069-66	Tests for Particulate and Dissolved Matter in Industrial Waste Water
D 1125-64 (1971)	Tests for Electrical Conductivity of Water
D 1126-67	Tests for Hardness in Industrial Water
D 1128-60 (1967)	Identification of Types of Microorganisms and Microscopic Matter in Industrial Water and Industrial Waste Water
D 1179-72	Tests for Fluoride Ion in Water
D1192-70	Specification for Equipment for Sampling Water and Steam
D 1193-72	Specification for Reagent Water
D 1246-68	Tests for Iodide and Bromide in Industrial Water and Industrial Waste Water
D 1252-67	Test for Chemical Oxygen Demand (Dichromate Oxygen Demand) of Waste Water
D 1253-68	Tests for Residual Chlorine in Industrial Water
D 1254-67	Tests for Nitrite Ion in Industrial Water
D 1293-65 (1970)	Test for pH of Industrial Water and Industrial Waste Water
D 1426-58 (1971)	Tests for Ammonia in Water
D 1427-68	Tests for Residual Chlorine in Industrial Waste Water
D 1428-64 (1971)	Tests for Sodium and Potassium in Water and Water-Formed Deposits by Flame Photometry
D 1589-60 (1967)	Tests for Dissolved Oxygen in Industrial Waste Water
D 1687-67	Tests for Total Chromium in Water
D 1688-68	Tests for Copper in Industrial Water and Industrial Waste Water
D 1690-61 (1967)	Measurement of Gamma Radioactivity of Industrial Water and Industrial Waste Water
D 1691-67	Tests for Zinc in Industrial Water and Industrial Waste Water
D 1782-72	Tests for Operating Performance of Particulate Cation Exchange Materials
D 1783-70	Tests for Phenolic Compounds in Water
D 1886-65 (1971)	Tests for Nickel in Water
D 1888-67	Tests for Particulate and Dissolved Matter in Industrial Water
D 1890-66 (1971)	Test for Beta Particle Radioactivity of Water
D 1943-66 (1971)	Measurement of Alpha Particle Radioactivity of Water
D 2036-72	Test for Cyanides in Water
D 2038-68	Test for Radioactive Barium in Industrial Water and Industrial Waste Water
D 2039-71	Test for Radioactive Manganese in Water
D2187-72	Test for Physical and Chemical Properties of Particulate Ion Exchange Resins
D 2330-68	Tests for Alkyl Benzene Sulfonate in Water
D 2333-68	Test for Thorium in Industrial Water and Industrial Waste Water
D 2334-68	Test for Radioactive Iodine in Industrial Water and Industrial Waste Water
D 2460-70	Test for Radionuclides of Radium

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ION EXCHANGE EQUIPMENT

	in Water
D 2461-69	Test for Iron-59 in Water
D 2470-70	Measurement of Delayed Neutron-Emitting Fission Products in Nuclear Reactor Coolant Water During Reactor Operation
D 2476-70	Test for Radioactive Tritium in Water
D 2576-70	Test for Metals in Industrial Water and Industrial Waste Water by Atomic Absorption Spectrophotometry
D 2577-72	Test for Radioactive Cesium in Water
D 2579-69	Tests for Total and Organic Carbon in Water by Combustion Infrared Analysis
D 2580-68	Test for Phenols in Water by Gas-Liquid Chromatography
D 2687-72	Sampling Particulate Ion Exchange Materials
D 2778-70	Test for Solvent Extraction of Organic Matter from Water
D 2791-69T	Continuous Determination of Sodium in High-Purity Water by Specific Ion Electrode
D 3081-72T	Test for Selenium in Water
D 3082-72T	Test for Boron in Water
D 3087-72	Test for Operating Performance of Anion Exchange Materials for Strong Acid Removal
F 57-68	Concentrating and Measuring Trace Quantities of Cooper in High Purity Water Used in the Electronics Industry
F 60-68	Detection and Enumeration of Microbiological Contaminants in Water Used for Processing Electron and Microelectronic Devices

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APPENDIX III

Suspended Iron Oxide Solids: Membrane Comparison Chart

The preparation of membrane comparison charts discussed in this Appendix is under consideration by Committee D-19 of ASTM for adoption as a standard method of measuring suspended iron oxide materials.

At this time, standard comparison charts for black iron oxide, hydrated iron oxide, and mixtures thereof, are commercially available from the Babcock & Wilcox Company, Barberton, Ohio.

Magnetite Standard Chart

This procedure describes the preparation of black iron oxide (Fe_3O_4) and deposition of the iron oxide on a 0.45 μ membrane filter.

Preparation of black iron oxide (Fe_3O_4): Add 0.1382 g of Fisher I 119 black iron oxide (Fe_3O_4) to clean 2-liter beaker. Add 1.0 liter of Reagent Grade water. This solution contains 100 ppm iron as Fe (Note1)

Stir vigorously (30 minutes) with a glass stirrer and stirring motor, suspended above the beaker.

Withdraw a 100 ml representative aliquot and dilute to a liter with Reagent Grade water (10 ppm Fe).

Add this solution to a clean 2-liter beaker and stir vigorously as above for ~30 minutes.

Withdraw a 100 ml representative aliquot and dilute to a liter with Reagent Grade water (1.0 ppm Fe).

Add this solution to a clean 2-liter beaker and stir vigorously for ~30 minutes.

Procedure for Membrane Preparation

Take an aliquot, as desired, while the solution is being stirred and filter through a 0.45 μ, type HA, 47 mm diameter Millipore paper. Use the Hydrosol Stainless Filter Assembly and Millipore (or equivalent) pump for filtering (assembly, pump, and filters are available through Millipore Corporation, Bedford, Mass.) The size of aliquots taken will depend on the desired amount of iron deposition equivalent to that accumulated from a one-liter throughput of sample water to the filter (Note 2).

Note 1: Reagent Grade chemicals and Reagent Grade water (ASTM D 1193-72) are used for this method. Use care to avoid iron contamination from glassware and apparatus used in this method.

Note 2: This procedure is intended for membrane strains up to 100 ppb iron (Fe). To obtain higher concentration, the iron concentration must be increased. Check the concentration to ensure that it is precisely 1.0 ppm by analysis using the orthophenanthroline method for iron (ASTM D1068-68).

If an iron analysis of the stain on the Millipore paper is desired, the paper should be treated as follows:

(a) Place paper disc in a 150-ml beaker and add 10 ml of reagent water, 2 ml perchloric acid, 2 ml sulfuric acid, and 2 ml nitric acid.

(b) Take the solution almost to dryness (less than 0.5 ml on a hot plate in a hood capable of handling perchloric acid fumes). In taking the solution to dryness it should be colorless. It is sometimes necessary to add more nitric acid dropwise until the solution loses its black color due to the presence of organic material.

(c) When the solution has been concentrated to dryness, cool, and add – for convenience of handling – 30 ml of reagent water and 5 ml hydrochloric acid.

(d) Bring the sample to a boil and digest for 5 minutes.

(e) Allow the sample to cool and dilute to a suitable volume in a volumetric flask. Determine the iron content colorimetrically by orthophenanthroline or bathophenanthroline (ASTM D1068-68).

Hydrated Iron Oxide Chart

This procedure describes the preparation of hydrated iron oxide ($Fe_2O_3 \cdot XH_2O$) and deposition of the iron oxide on an 0.45 μ membrane filter (Notes 1, and 2 for the magnetite chart apply).

Hydrated iron oxide ($Fe_2O_3 \cdot XH_2O$) – dissolve 0.7022 g of ferrous ammonium sulfate $[Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O]$ in approximately 500 ml of Reagent Grade water.

Add 20 ml of sulfuric acid (H_2SO_4) sp gr 1.84, and 10 ml of 30 percent hydrogen peroxide (H_2O_2) and heat to boiling. Maintain slow boiling for 30 minutes to ensure complete oxidation.

Cool the solution to ambient temperature and dilute to a liter with Reagent Grade water (100 ppm Fe).

Dilute 100 ml of the above 100 ppm Fe solution to a liter with Reagent Grade water (10 ppm Fe).

Transfer 100 ml of the 10 ppm Fe solution to a 400-ml beaker and adjust the pH to 10.5-11.0 using ~1.0 N sodium hydroxide (NaOH). Dilute to a liter with Reagent Grade water (1.0 ppm Fe).

Transfer this 1.0 ppm Fe solution to a 2-liter beaker and stir vigorously with a glass stirrer and stirring motor suspended above the beaker. Cover the beaker with plastic wrap to prevent contamination.

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Procedure for Membrane Stain Preparation

Take an aliquot, as desired, while the solution is being stirred and filter through a 0.45 μ, Type HA, 47 mm diameter Millpore paper. Use the Hydrosol Stainless Filter Assembly and Millipore pump (or equivalent) for filtering. The size of aliquots taken will depend on the desired amount of iron deposition equivalent to that accumulated from a one-liter throughput of sample water to the filter.

Mixed Hydrated Oxide: Magnetite 1:1 Standard Chart

This procedure describes the preparation of a mixture of iron oxides ($Fe_2O_3 \cdot XH_2O$ and Fe_3O_4) and deposition of the oxides on an 0.45 μ membrane filter (Notes 1, and 2 for the magnetite chart apply).

Hydrated iron oxide ($Fe_2O_3 \cdot XH_2O$). Black iron oxide (Fe_3O_4) mixture 1:1. Dissolve 0.7022 g of ferrous ammonium sulfate [$Fe(NH_4)_2 (SO_4)_2 \cdot 6H_2O$] in ~ 500 ml of Reagent Grade water.

Add 20 ml of sulfuric acid (H_2SO_4) sp gr 1.84, and 20 ml of 30 percent hydrogen peroxide (H_2O_2) and heat to boiling. Maintain boiling (slow) for ~ 30 minutes to ensure complete oxidation.

Cool the solution to ambient temperature and adjust the pH to 10.5-11.0 using ~1.0 N sodium hydroxide (NaOH). Dilute to a liter with Reagent Grade water (100 ppm Fe).

This solution is to be combined later with the black iron oxide (Fe_3O_4) solution.

Add 0.1382 g of Fisher I-119 black iron oxide (Fe_3O_4) to a liter volumetric flask and dilute to the mark with Reagent Grade water (100 ppm Fe).

Combine the solutions in a clean 3-liter beaker and stir vigorously for ~30 minutes with a glass stirrer and stirring motor suspended above the beaker. Cover the beaker with plastic wrap to prevent contamination.

While vigorously stirring, withdraw a 100-ml representative aliquot and dilute to 2 liters with Reagent Grade water (5 ppm Fe solution).

Transfer this solution to a clean 3-liter beaker and stir vigorously for ~30 minutes.

Procedure for Membrane Stain

Take an aliquot, as desired, while the solution is being stirred and filter through a 0.45 μ, Type HA, 47 mm diameter Millipore paper. Use the Hydrosol Stainless Filter Assembly and Millipore pump for filter ing. The size of aliquots taken will depend on the desired amount of iron deposition equivalent to that accumulated from a one-liter throughput of sample water to the filter.

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PERFORMANCE TEST CODES

PERFORMANCE TEST CODES NOW AVAILABLE

PTC 4.3 – Air Heaters . . . . . (1968)
PTC 23 – Atmospheric Water Cooling Equipment. . . . . (1958)
PTC 8.2 – Centrifugal Pumps . . . . . (1965)
PTC 4.2 – Coal Pulverizers . . . . . (1969)
PTC 10 – Compressor and Exhausters . . . . . (1965)
PTC 2 – Definitions and Values . . . . . (1971)
PTC 9 – Displacement Compressors, Vacuum Pumps and Blowers . . . . . (1970)
PTC 7.1 – Displacement Pumps . . . . . (1962)
PTC 12.3 – Deaerators . . . . . (1958)
PTC 27 – Determining Dust Concentration in a Gas Stream . . . . . (1957)
PTC 28 – Determining the Properties of Fine Particulate Matter . . (1965)
PTC 3.1 – Diesel and Burner Fuels . . . . . (1958)
PTC 21 – Dust Separating Apparatus . . . . . (1941)
PTC 24 – Ejectors and Boosters . . . . . (1956)
PTC 14 – Evaporating Apparatus . . . . . (1970)
PTC 12.1 – Feedwater Heaters . . . . . (1955)
PTC 16 – Gas Producers and Continuous Gas Generators . . . . . (1958)
PTC 22 – Gas Turbine Power Plants . . . . . (1966)
PTC 3.3 – Gaseous Fuels . . . . . (1969)
PTC 1 – General Instructions . . . . . (1970)
PTC 18 – Hydraulic Prime Movers . . . . . (1949)
PTC 31 – Ion Exchange Equipment . . . . . (1973)
PTC 32.1 – Nuclear Steam Supply Systems. . . . . (1969)
PTC 20.2 – Overspeed Trip Systems for Steam Turbine-Generator Units . . . . . (1965)
PTC 20.3 – Pressure Control Systems Used on Steam Turbine-Generator Units . . . . . (1970)
PTC 17 – Reciprocating Internal-Combustion Engines . . . . . (1973)
PTC 7 – Reciprocating Steam-Driven Displacement Pumps . . . . . (1949)
PTC 5 – Reciprocating Steam Engines . . . . . (1949)
PTC 25.2 – Safety and Relief Valves . . . . . (1966)
PTC 3.2 – Solid Fuels . . . . . (1954)
PTC 29 – Speed-Governing Systems for Hydraulic Turbine-Generator Units . . . . . (1965)
PTC 26 – Speed-Governing Systems for Internal Combustion Engine-Generator Units . . . . . (1962)
PTC 20.1 – Speed-Governing Systems for Steam Turbine-Generator Units . . . . . (1958)
PTC 12.2 – Steam Condensing Apparatus. . . . . (1955)
PTC 4.1 – Steam-Generating Units . . . . . (1964)
PTC 6 – Steam Turbines . . . . . (1964)
PTC 6A – Appendix A to Test Code for Steam Turbines . . . . . (1964)
PTC 6 Report – Guidance for Evaluation of Measurement – Uncertainty in Performance Tests of Steam Turbines (1969)
PTC 6.1 – Interim Test Code for Steam Turbines Operating Predominantly Within the Moisture Region With Nuclear Steam Supply . . . . . (1972)
PTC 6S Report – Simplified Procedures for Routine Performance Tests of Steam Turbines . . . . . (1970)

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