ASME TES-1–2020

Safety Standard for Thermal Energy Storage Systems: Molten Salt

AN AMERICAN NATIONAL STANDARD

The American Society of Mechanical Engineers

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Two Park Avenue • New York, NY • 10016 USA

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The next edition of this Standard is scheduled for publication in 2023. This Standard will become effective 6 months after the Date of Issuance.

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

Errata to codes and standards may be posted on the ASME website under the Committee Pages to provide corrections to incorrectly published items, or to correct typographical or grammatical errors in codes and standards. Such errata shall be used on the date posted.

The Committee Pages can be found at http://cstools.asme.org/. There is an option available to automatically receive an e-mail notification when errata are posted to a particular code or standard. This option can be found on the appropriate Committee Page after selecting "Errata" in the "Publication Information" section.

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

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FOREWORD

In July 2013, the American Society of Mechanical Engineers (ASME) conducted a survey of industry professionals on thermal energy storage (TES). The results indicated interest in the development of standards or guidance documents for the TES sector. ASME again surveyed industry professionals in May 2014 and determined that the proposed standard or guide should focus on safety related to electrical utility applications, specifically TES systems. The results also suggested that the standard should be suitable for use by manufacturers, owners, designers, and others concerned with or responsible for the application of prescribed safety requirements.

A group was formed from the list of survey respondents to discuss the development of an initial TES standard or guideline. This group met on a monthly basis throughout the latter part of 2014 until June 2015. Based on their efforts, ASME formed a Safety Standards Committee for Thermal Energy Storage Systems (TES Safety Standards Committee) in June 2015. At that time the TES committee charter and membership were approved by ASME.

The purpose of the committee is to develop and maintain safety standards covering the design, construction, installation, inspection, testing, commissioning, maintenance, operation, and decommissioning of TES systems. Recognizing the range of TES technologies, the TES Safety Standards Committee decided to initially focus on one technology, molten salt TES systems. Following the completion of this task, the Committee will address standards or guides for other TES systems.

Since late 2015, the TES Safety Standards Committee has worked to develop a safety standard for molten salt TES systems. ASME TES-1–2020 is the result of these efforts. The American National Standards Institute approved ASME TES-1-2020 as an American National Standard on March 11, 2020.

ASME TES COMMITTEE
Thermal Energy Storage Systems

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

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CORRESPONDENCE WITH THE TES COMMITTEE

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

Secretary, TES Standards Committee
The American Society of Mechanical Engineers
Two Park Avenue
New York, NY 10016-5990
http://go.asme.org/Inquiry

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

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

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

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

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

Requests for interpretation should preferably be submitted through the online Interpretation Submittal Form. The form is accessible at http://go.asme.org/InterpretationRequest. Upon submittal of the form, the Inquirer will receive an automatic e-mail confirming receipt.

If the Inquirer is unable to use the online form, he/she may mail the request to the Secretary of the TES Standards Committee at the above address. The request for an 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 in one or two words.

Edition: Cite the applicable edition of the Standard 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. Please provide a condensed and precise question, composed in such a way that a "yes" or "no" reply is acceptable.

Proposed Reply(ies): Provide a proposed reply(ies) in the form of "Yes" or "No," with explanation as needed. If entering replies to more than one question, please number the questions and replies.

Background Information: Provide the Committee with any background information that will assist the Committee in understanding the inquiry. The Inquirer may also include any plans or drawings that are necessary to explain the question; however, they should not contain proprietary names or information.

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

Moreover, ASME does not act as a consultant for specific engineering problems or for the general application or understanding of the Standard requirements. If, based on the inquiry information submitted, it is the opinion of the Committee that the Inquirer should seek assistance, the inquiry will be returned with the recommendation that such assistance be obtained.

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 TES Standards Committee regularly holds meetings and/or telephone conferences that are open to the public. Persons wishing to attend any meeting and/or telephone conference should contact the Secretary of the TES Standards Committee.

INTRODUCTION

Solar energy may be the leading renewable energy source, but storage challenges have limited its adoption by, among others, utilities. Thanks to innovations in thermal energy storage in megawatt-hour quantities, solar thermal energy has become more feasible for large-scale applications.

Thermal energy can be stored in sensible, latent, or chemical form. The storage of industrial quantities of thermal energy is in a nascent stage and primarily consists of sensible heat storage in nitrate salt eutectics and mixtures. The requirements and guidance described in this Standard are for the safe implementation of thermal energy storage in the generation of electrical power using a sensible heat method.

This Standard describes practices for designing and implementing thermal energy storage (TES) for large applications. These usually involve two-tank sensible heat systems using molten salts. The practices described in this Standard are to be used during factory manufacture and on the jobsite. The team implementing the Standard is expected to have a working knowledge of hydraulics, materials, electrical systems and controls, thermal energy fundamentals, applicable referenced standards, field test measurement methods, and how to use test and measurement equipment needed to meet these requirements.

This Standard was prepared with attention to other standards for energy storage systems. The tests described are useful in establishing compliance with other related standards.

SAFETY STANDARD FOR THERMAL ENERGY STORAGE SYSTEMS: MOLTEN SALT

1 SCOPE

This Standard establishes requirements for the design, construction, installation, inspection, testing, commissioning, maintenance, operation, and decommissioning of molten salt thermal energy storage (TES) systems. Molten salt thermal energy systems include the storage medium and associated storage vessels, controls for the system, and associated system components such as circulation pumps, valves, piping, and heat exchangers that are in contact with molten salt.

The following components are not included within the scope of this Standard:

(a) the solar receiver and parabolic trough system and associated heat transfer fluid piping

(b) solar field

(c) steam and water piping and associated pumps

(d) power block

(e) auxiliary heater

Figures 1-1 and 1-2 provide examples of molten salt TES systems.

2 DEFINITIONS

cladding: the weather-proof jacketing on the outside of any thermal insulation.

design basis document: the set of instructions establishing the owner-defined criteria (objectives, conditions, needs, requirements, etc.) the design engineering organization takes into account when designing the project.

designer: the person or organization in charge of the engineering design. The designer is responsible for complying with standards and regulations and demonstrating this compliance with equations when such equations are mandatory.

manufacturer: the person or organization responsible for the construction of the structural, mechanical, piping, and/or electrical equipment and components in accordance with the rules of this Standard and the requirements of the design.

molten salt: the liquid state of a salt mixture such as sodium nitrate and potassium nitrate. Molten salts are useful as a thermal storage medium and heat transfer fluid in TES systems.

owner: for the purposes of this Standard, the party ultimately responsible for the operation of a facility. The owner is the party licensed by the regulatory authority having jurisdiction; that is, the party with administrative and operational responsibility for the facility, including the planning activities described in para. 4.1. The owner may hire a third-party service provider to operate and maintain the TES system on its behalf.

purchaser: the owner of the TES system or the owner's designated agent.

NOTE: A single entity may fill one or more of the roles defined in the Definitions list.

3 REFERENCES

The codes, standards, and specifications listed in this section contain provisions that, to the extent referenced in this Standard, constitute requirements of this Standard.

API 510-2014, Pressure Vessel Inspection Code: In-Service Inspection, Rating, Repair, and Alteration

API 570-2016, Piping Inspection Code: In-Service Inspection, Rating, Repair, and Alteration of Piping Systems

API RP 580-2009, Risk-Based Inspection

API RP 2003-2015, Protection Against Ignitions Arising Out of Static, Lightning, and Stray Currents

API STD 610-2010, Centrifugal Pumps for Petroleum, Petrochemical and Natural Gas Industries

API STD 620-2013, Design and Construction of Large, Welded, Low-Pressure Storage Tanks

API STD 650-2013, Welded Tanks for Oil Storage

API STD 653-2014, Tank Inspection, Repair, Alteration, and Reconstruction

API STD 2000-2014, Venting Atmospheric and Low-Pressure Storage Tanks

API STD 2015-2018, Requirements for Safe Entry and Cleaning of Petroleum Storage Tanks

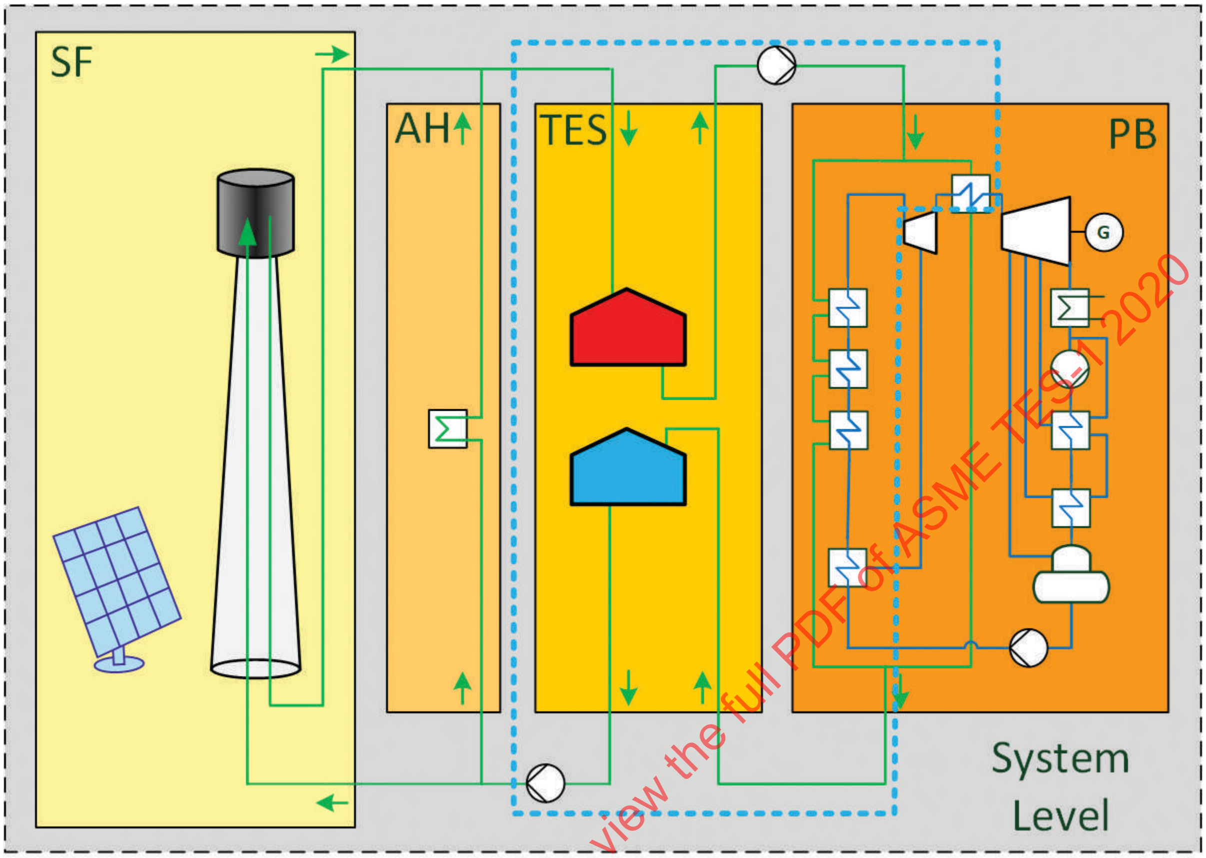
Publisher: American Petroleum Institute (API), 200 Massachusetts Avenue NW, Suite 1100, Washington, DC 20001-5571 (www.api.org)

ASME A13.1-2015, Scheme for the Identification of Piping Systems

ASME B31.1-2018, Power Piping

ASME B31.3-2016, Process Piping

Figure 1-1 TES for a Concentrated Solar Power Tower System



GENERAL NOTES:
(a) Graphic courtesy of SolarPACES Guideline for Bankable STE Yield Assessment.
(b) Terms for molten-salt power tower subsystems are defined as follows:
AH = auxiliary heater
PB = power block
SF = solar field
TES = thermal energy storage
(c) Blue dashed box indicates the systems covered in this Standard.

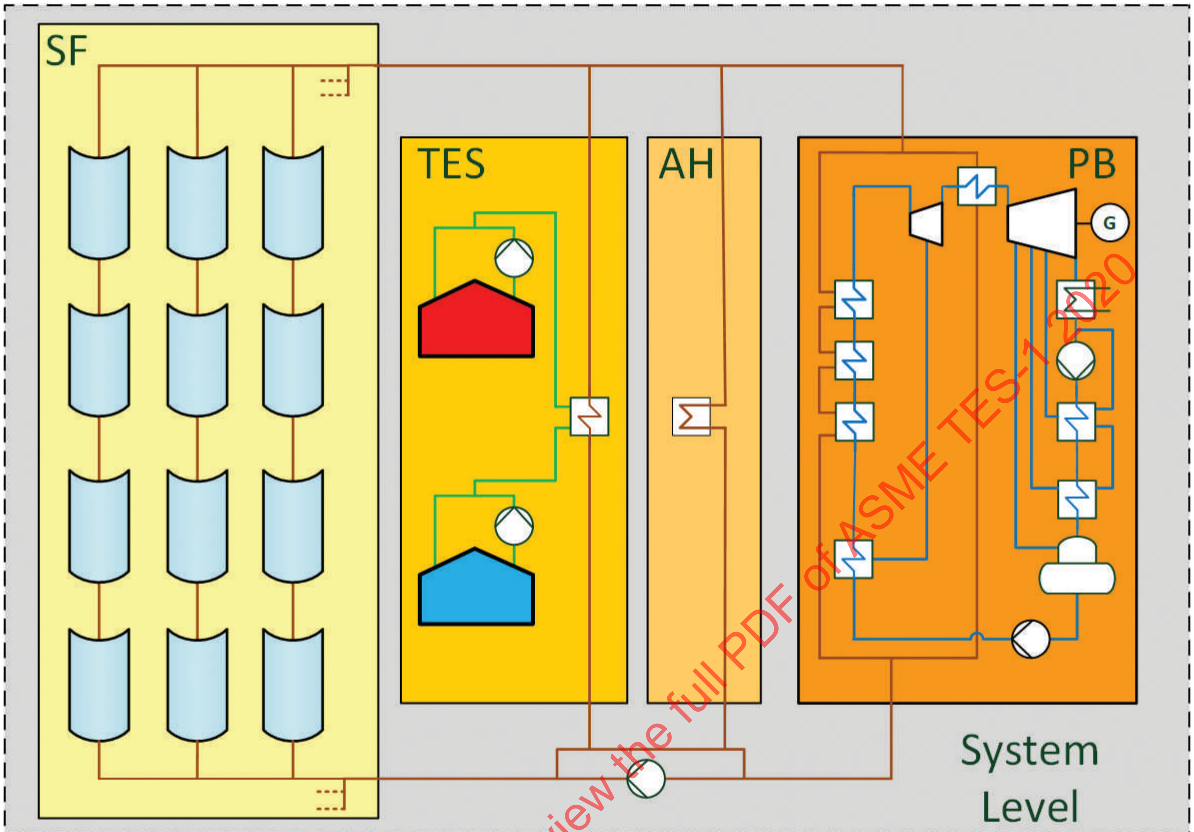
ASME Boiler and Pressure Vessel Code (BPVC) 2019
Section II, Materials, Part D
Section VIII, Rules for Construction of Pressure Vessels, Divisions 1 and 2
ASME PCC-3–2017, Inspection Planning Using Risk-Based Methods
ASME PTC 19.1-2018, Test Uncertainty
ASME PTC 19.2-2015, Pressure Measurement
ASME PTC 19.3 TW-2016, Thermowells
ASME PTC 19.5-2013, Flow Measurement
Publisher: The American Society of Mechanical Engineers (ASME), Two Park Avenue, New York, NY 10016-5990 (www.asme.org)

IEEE 515-2017, IEEE Standard for the Testing, Design, Installation, and Maintenance of Electrical Resistance Trace Heating for Industrial Applications
Publisher: Institute of Electrical and Electronics Engineers (IEEE), 445 Hoes Lane, Piscataway, NJ 08854-4141 (www.ieee.org)

ISO 12212:2012, Petroleum, petrochemical and natural gas industries — Hairpin-type heat exchangers
ISO 15547-1:2005, Petroleum, petrochemical and natural gas industries — Plate-type heat exchangers — Part 1: Plate-and-frame heat exchangers
Publisher: International Organization for Standardization (ISO), Central Secretariat, Chemin de Blandonnet 8, Case Postale 401, 1214 Vernier, Geneva, Switzerland (www.iso.org)

NBBI NB23-2017, National Board Inspection Code

Figure 1-2 TES for Parabolic Trough Plant



GENERAL NOTES:
(a) Graphic courtesy of SolarPACES Guideline for Bankable STE Yield Assessment.
(b) Terms for parabolic trough plant subsystems are defined as follows:
AH = auxiliary heater
PB = power block
SF = solar field
TES = thermal energy storage

Publisher: The National Board of Boiler and Pressure Vessel Inspectors (NBBI), 1055 Crupper Avenue, Columbus, Ohio 43229-1183 (www.nationalboard.org)

NFPA 70-2017, National Electric Code
NFPA 704-2017, Standard System for the Identification of the Hazards of Materials for Emergency Response
NFPA 780-2017, Standard for the Installation of Lightning Protection Systems
Publisher: National Fire Protection Association (NFPA), 1 Batterymarch Park, Quincy, MA 02169-7471 (www.nfpa.org)

TEMA-2019, Standards of the Tubular Exchanger Manufacturers Association
Publisher: Tubular Exchanger Manufacturers Association, Inc. (TEMA), 25 North Broadway, Tarrytown, NY 10591 (www.tema.org)

4 PLANNING AND DESIGN

4.1 Planning

Planning shall be conducted in a manner that supports the safety of the molten salt TES system from system design initiation through construction, installation, testing, commissioning, maintenance, and operation, ending with its decommissioning. Planning shall identify special precautions that shall be taken to protect operating personnel and personnel working near the molten salt TES system.

The designer shall take the following steps during the planning phase of the project:

Step 1. Develop a design basis document that includes
(a) system description
(b) scope of supply
(c) design codes and standards

(d) general design requirements

(e) specific design requirements (e.g., design temperature, heat rate, thermal cycles)

(f) material requirements

(g) salt specification

Step 2. Identify and consider environmental and relevant site-related issues associated with the proposed project.

Step 3. Conduct hazard analysis, such as failure modes and effects analysis (FMEA), hazards and operability study (HAZOP), or hazard mitigation analysis (HMA).

Step 4. Prepare a project-specific safety-basis document that defines the safety analysis and hazard mitigation controls intended to ensure that the molten salt TES system can be operated in a manner that protects workers, the public, and the environment.

Step 5. Identify and comply with laws, rules, and regulations applicable to the project site and the proposed project.

Step 6. Preliminarily develop a commissioning plan as described in para. 5.2, an operations and maintenance manual as described in para. 6.3, and an emergency response plan as described in para. 5.2.4.

Step 7. Provide means to contain any possible leaks from the system.

4.2 Design

Molten salt TES systems shall be designed in accordance with the provisions of this Standard. The design of the system shall also comply with the instructions provided by the manufacturer of the equipment, controls, and other components comprising the system. Any change in design requirements or material substitutions by the manufacturer shall be approved by the designer.

4.2.1 General

(a) The system shall be designed to withstand the specified temperature and pressure conditions of the molten salt.

(b) Systems employing nitrate salts that may exceed 450°C (842°F) shall be designed to safely manage vaporization of the salt and production of oxygen and NOx gas from salt decomposition.

(c) The system shall be designed to take into consideration the quality and level of impurity of the molten salt and any possible contaminants that could be introduced into the molten salt.

(d) The system shall be designed to relieve excessive internal pressure caused by accidental steam flashing or chemical reactions of the nitrate molten salt system.

(e) The system shall be designed to safely contain or relieve pressures where there is a possibility that the salts and the heat transfer fluids can be mixed.

4.2.2 Signs and Labeling. All equipment shall be labeled and signage shall be provided in accordance with ASME A13.1 or in accordance with local regulations.

(a) Molten salt storage tanks shall be marked to identify the

(1) associated hazards in accordance with NFPA 704

(2) tank number

(3) type of molten salt

(4) maximum allowable amount of salt in the tank by weight

(5) maximum operating pressure and temperature

(b) All heat exchangers shall have signs indicating the maximum operating temperature of the heat exchanger in accordance with the standard to which it is manufactured. Signage shall include the chemical formula or types of salt(s) that are suitable for use in the system.

(c) All system components with a heat tracing system shall have labels indicating the presence of heat tracing. The heat trace itself shall include a permanent marking indicating its maximum operating temperature. Cladding shall be marked with the heat trace manufacturer's warning label indicating that the equipment is heat traced. Stainless steel tags shall be affixed to all heat trace elements indicating circuit information.

4.2.3 Storage Tank Systems

4.2.3.1 Tank Requirements. The minimum requirements for the design, construction, installation, commissioning, inspection, and decommissioning of molten salt storage tanks are provided herein. These requirements shall also apply to piping connected internally or externally to the roof, shell, or bottom of the tank up to the face of the first flange of bolted connections, the first threaded joint on threaded pipe connections, and the first circumferential joint in welding-end pipe connections that are not welded to a flange.

Compliance with the following requirements shall be the responsibility of the tank designer:

(a) Tanks shall be made of metal of welded construction.

(b) Tanks shall be designed for an internal pressure not exceeding 103 kPa (15 psi) in the tank or portions of the tank enclosing gas or vapor.

(c) Tanks shall be freestanding with fixed roofs.

(d) Tanks shall be designed in anticipation of corrosion problems during the life of the TES system and in accordance with the applicable requirements of API STD 620 or API STD 650, subject to the modifications and limitations regarding high temperatures in this Standard.

(e) Tanks shall be evaluated for thermal stress with consideration for the start-up procedure (preheating of the tank), the initial filling of the tank, temperature stratification limits and other temperature conditions, and the frictional resistance between the tank bottom and the tank foundation associated with radial thermal expansion.

(f) Tanks shall be evaluated for anticipated fatigue due to cyclic temperature and filling conditions during the life of the tank in accordance with ASME BPVC, Section VIII, Division 2.

(g) The size and dimensions of each tank shall account for

(1) volume and density of the salt

(2) expected heat loss through the tank

(3) net positive suction head associated with the molten salt pumps

(4) soil conditions associated with the site

(5) any limitations associated with applicable zoning or construction regulations

(6) restrictions associated with the site that will affect the fabrication and erection of the tank

(h) The metallic materials used in the construction of tanks shall be selected based on the TES process and mechanical requirements at the system operating temperatures. The following shall also be considered:

(1) mechanical properties relevant to the tank such as tensile strength, Young's modulus, toughness, hardness, fatigue resistance, and creep resistance

(2) the effects of normal operating temperatures as well as maximum possible temperatures on the mechanical properties

(3) corrosion resistance and salt contamination

(i) When determining the maximum allowable stress on the tank material at design temperature, the effects of anticipated temperatures on the tensile strength, yield strength, and creep resistance of the material shall be taken into consideration. The tensile and yield strength values and physical properties for materials used in tank construction as a function of temperature shall be obtained from ASME BPVC, Section II, Part D. When not listed there, those values shall be provided with the plans and specifications for the tank. Each tank shall be designed using the quality factors and welded-joint efficiency factors of API STD 620 or API STD 650, subject to the modifications and limitations regarding high temperatures in this Standard.

(j) The welded joints associated with the shell and bottom of the tank shall be butt joints with complete penetration and complete fusion attained by double welding or other means that obtain the same quality of deposited metal throughout the weld. The roof of the tank shall be either lap welded or butt welded.

(k) All tank construction shall have butt-welded annular bottom plates.

(l) The attachment between the bottom edge of the lowest course shell plate and the tank bottom shall be a double fillet-groove weld.

(m) Nondestructive examination, inspection, and hydrostatic testing of all tanks shall be done in accordance with API STD 620 or API STD 650, subject to the modifications and limitations regarding high temperatures in this Standard.

(n) Tanks shall be identified by a nameplate containing at a minimum the information depicted in Figure 4.2.3.1-1. Information on the nameplate shall be clearly stamped using letters and numerals not less than 4 mm ($^5\!/_{32}$ in.) high. At the purchaser's request, or at the manufacturer's discretion, additional pertinent information may be shown on the nameplate, and the size of the nameplate may be increased proportionately. The nameplate shall be displayed in such a manner that it is visible after insulation has been installed.

(o) All tanks shall be provided with a minimum of four grounding lugs equally spaced at a maximum of 30 m (100 ft) apart in accordance with API RP 2003 and NFPA 780.

(p) In addition to the requirements in (a) through (o), the tank designer shall consider

(1) whether to choose an external, internal, or combined external-internal tank insulation system

(2) whether to apply a system capable of preheating the empty tank prior to initial filling with salt

(3) the manner in which tank appurtenances have been designed to withstand anticipated external loads

4.2.3.2 Tank Foundation. The requirements herein apply to the structures that provide a foundation for tanks storing molten salt.

(a) The tank designer shall provide the following information to the individual(s) responsible for the design of the tank foundation:

(1) all static and dynamic tank loads to be supported by the foundation structure for both test and operating conditions, including applicable wind and seismic loads

(2) the tank's dimensional tolerances and the minimum dimensions necessary to ensure the foundation and interface elements will accommodate the tank

(3) the operating temperature of the tank bottom and any insulation to be installed under the tank bottom

(4) expected thermal expansion of the tank during test and operating conditions

(b) The tank foundation drawings shall provide the necessary information to document compliance with (a) and include the following:

(1) reference to project specification

(2) reference to any necessary geotechnical/soil reports

(3) table of loads imposed on the foundation by the tank and bearing values of the soil supporting the foundation and tank

(4) statements defining responsibilities for furnishing and installation of materials

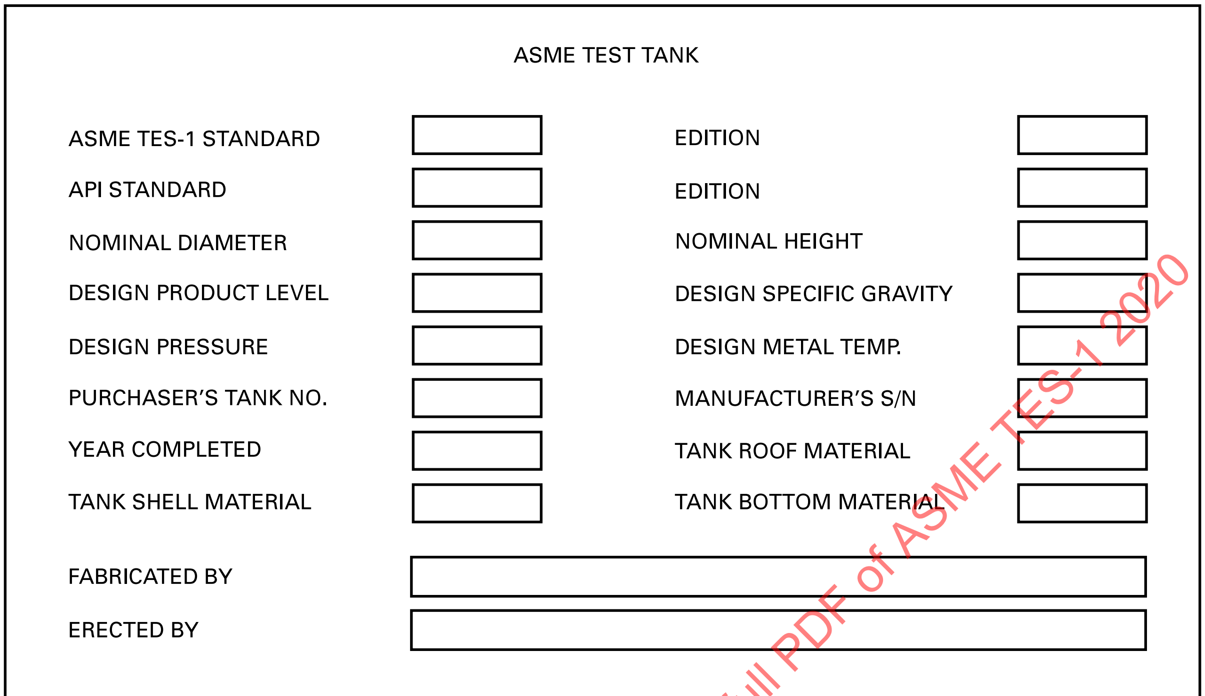
(5) the required compressive strength of concrete

(6) the reinforcing steel specification

(7) specifications for other material in the foundation

(8) methods of placing and compacting backfill materials

Figure 4.2.3.1-1 Tank Name Plate



(9) tolerances for placement of embedded items and for ensuring that the top of the foundation is level

(c) The tank shall rest on an engineered grade or engineered perimeter ringwall. The tank foundation shall be designed to account for anticipated uneven settling of the tank and to minimize corrosion to any part of the tank resting on the foundation.

(d) The tank foundation shall be designed and constructed to support the tank at the design temperatures associated with the tank contents. Any insulating system and associated cooling systems intended to isolate the foundation from the temperatures in the tank shall be considered while determining the temperatures to which the foundation materials will be exposed.

(e) A foundation cooling system shall be used when required to maintain the foundation at a temperature acceptable to the foundation materials selected (e.g., forced-air, passive air, or water-cooled system).

(f) The tank purchaser shall specify whether the area under the tank is to be constructed for leak detection and the method(s) to be employed.

(g) The foundation design shall incorporate grounding and bonding provisions designed to function in conjunction with para. 4.2.3.1(o).

4.2.3.3 Tank Insulation. The requirements herein apply to the insulation system used to control heat loss from the tank storing molten salt to both surrounding ambient conditions and the foundational structures supporting the tank.

(a) Insulation shall be suitable for the intended temperatures associated with the service.

(b) Insulation located on the exterior of the tank or exposed to the weather or other exterior conditions shall have weathering, UV, and mechanical resistance properties necessary to withstand the anticipated service conditions of the tank.

(c) Insulation located on the interior of the tank shall have the ability to withstand the anticipated mechanical loads and offer chemical resistance to corrosion anticipated from long-term exposure to the type of molten salt stored in the tank.

(d) The operating temperature of exposed tank surfaces during normal operation shall not exceed 60°C (140°F); otherwise, the tank surfaces shall be protected to preclude contact.

4.2.3.4 Tank Immersion Heaters. The requirements herein apply to the heaters immersed into tanks storing molten salt.

(a) Immersion heaters shall have the capacity to produce make-up heat to account for thermal loss associated with the overall tank system.

(b) Immersion heaters shall have a sheath surface temperature consistent with the tank contents, and shall have temperature controls to ensure the heater

will maintain the molten salt within its design temperature range.

(c) Immersion heaters shall be protected against overheating of the heating element.

(d) Immersion heaters shall automatically shut off when the molten salt reaches its temperature set point.

(e) The design of the molten salt system shall prevent physical access to the immersion heater while any pressure exists in the tank.

(f) The design shall make it possible to isolate the heater for maintenance.

(g) Immersion heaters shall have automatic controls to ensure the heaters are operational only when the elements of the heater are fully submersed in molten salt.

(h) Immersion heaters shall have ground fault protection and a manual means of disconnection in accordance with NFPA 70.

(i) When an immersion heater uses a thyristor/silicon-controlled rectifier (SCR) to provide power switching, the SCR controller shall automatically detect a shorted SCR condition, provide alarm indication, and shut down the heater.

4.2.3.5 Tank Venting and Blanketing

(a) Molten salt storage tanks shall be vented to prevent the development of a vacuum or pressure sufficient to distort the tank during filling or emptying. The vents shall be sized in accordance with API STD 2000.

(b) Molten salt storage tanks shall have a means to relieve internal pressure above the maximum design pressure.

(c) Molten salt storage tank relief devices shall be protected against the solidification of salt mist within or at the inlet to the device.

(d) Vent piping shall direct the effluent from the device to a safe location and away from personnel, areas of the system providing essential services, and other equipment.

(e) Venting of the gas stream to the environment shall be in accordance with local regulations.

(1) Where regulations allow direct NOx discharge, vents shall discharge the gas stream at a height and location that prevents drift into areas associated with the system that are providing essential services, such as building and system controls and the receiver system tower structure.

(2) Systems that use nitrate salts and exceed 480°C (900°F) during normal operation shall have the venting system and its component parts designed to resist degradation from nitric acid.

(f) When the molten salt storage tanks are provided with blanketing, the blanketing shall be compatible with the salt composition.

4.2.3.6 Tank Instrumentation

(a) The tank shall have instrumentation to measure and report the level and temperature of the molten salt and pressure inside the tank. This instrumentation shall meet the requirements of ASME PTC 19.2 and ASME PTC 19.3.

(b) Instrumentation for tank pressure and salt level shall be protected to prevent salt solidification on the instrumentation.

(c) The number and location of temperature measurements shall consider variation of temperature within the tank.

4.2.3.7 Tank Leakage

(a) Means shall be provided to contain any possible leaks from the tank. Such means shall be capable of containing the entire volume of salt in the tank.

(b) The location of the containment area shall minimize the impact of any leaks on the external environment and shall be designed to facilitate removing tank contents that have solidified as a result of a leak.

4.2.3.8 Sampling. Access shall be provided to allow periodic sampling of the salt to detect salt contaminants and monitor salt composition.

4.2.4 Molten Salt Circulation Pumps

(a) All materials used in the pump assembly, including the bellows, shall be suitable for the design life, temperatures, and pressures associated with contact with the salt.

(b) The pump pressure casing and nozzle(s) shall be designed for the maximum operating pressure throughout the expected operating temperature range, from minimum ambient to maximum design temperatures, and include a pump deadhead pressure condition.

(c) Pump assembly anchorage shall be sized for the maximum operational loads, heat dissipation, and environmental site conditions associated with the molten salt system.

(d) Heat tracing and insulation shall be used where required to prevent solidification of the salt. Placement of the insulation for the pump assembly shall be in accordance with the specifications provided by the pump manufacturer.

(e) Pumps shall have means to connect to and lift the pump at the maximum design temperature.

(f) For pumps mounted in a vertical position, the shaft seal arrangement associated with the pump assembly and all system connections to the pump shall be designed to prevent leakage of molten salt and shall include both a primary and secondary seal. The pump-to-tank bellows associated with the pump shall be sized in accordance with the specifications provided by the manufacturer of the pump and with the design and installation of the salt tank and foundation structure for the pump.

(g) The pump assembly that circulates molten salt shall be hydrostatically tested by the manufacturer in accordance with API STD 610.

(h) The pump shall be designed and installed to prevent thrust loads from the pump or thermal expansion of the pump shaft from stressing the pump driver.

(i) When a pump is not submerged in molten salt, the pump shall have means to prevent frozen salt conditions in the pump volute.

(j) The lower radial bearings and journal sleeves shall be capable of dry running at start-up and shutdown.

(k) The pump design shall permit the replacement of the thrust bearing without removal of the molten salt pump from the tank.

(l) Pumps and motors shall have vibration monitoring and protections.

(m) Pumps and motors shall have bearing temperature monitoring and protection to prevent failure. Over temperature trips shall shut down a pump.

(n) Motors shall have current-monitoring system that shall shut down the motor if the current exceeds a set limit.

(o) Reverse rotation protection shall be provided.

4.2.5 TES Piping Systems

(a) Piping systems shall be designed, fabricated, examined, and tested in accordance with the requirements of ASME B31.1 or ASME B31.3.

(b) The materials used in piping systems shall be of suitable design for the anticipated operating pressures and temperatures in the system. Materials shall be compatible with the type of molten salt used in the system.

(c) Piping systems shall be provided with valves to allow isolation from the tanks, pumps, and heat exchangers associated with the molten salt system. Valves, seats, packing, and seals shall be selected based on material compatibility with the type of molten salt used in the system. Valves shall not be capable of an adverse reaction to the type of molten salt used in the system; such adverse reactions include, but are not limited to, metal fires.

(d) Each separate piece of equipment in the system shall be capable of being isolated and shall have a drain plug or valve to allow for drainage.

(e) The piping system shall be designed to

(1) minimize the number of dead-end branches that can result in stagnation of the molten salt flow

(2) withstand pressure, weight, seismic, wind, thermal expansion, and other anticipated loads

(3) ensure that the entire system can be drained by gravity back into one of the storage tanks or a tank designated for that purpose

(4) avoid loads on joints and interfaces with equipment that would exceed the allowable force and moment limitations at all anticipated system pressures and temperatures

(5) ensure any bellows located in a piping system shall accommodate anticipated movement

(6) include zones with heat-tracing and temperature-monitoring system that will immediately alert the control room when the salt temperature falls below the minimum operating temperature of the system.

(f) The operating temperature of exposed pipe surfaces during normal operation shall not exceed 60°C (140°F); otherwise, the pipe surfaces shall be protected to preclude contact.

4.2.6 Heat Exchanger Systems

(a) Heat exchangers that handle molten salt shall be made of materials and be of a design that will support the temperature and pressure conditions and liquids or gases to which they will be subjected during operation, construction, commissioning, and testing.

(b) Tubular-type heat exchangers shall be built in accordance with TEMA Class R standards. Shell construction types shall be selected from the TEMA-designated shell types for single-phase and phase-change heat exchangers, including shell type K (kettle reboilers). Front- and rear-head types and all other features of tubular-type heat exchangers shall be built in accordance with the TEMA-defined types for these units. Hairpin exchangers shall be constructed in accordance with ISO 12212. Plate-type heat exchangers shall be constructed in accordance with ISO 15547-1.

(c) Heat exchangers shall have a pressure relief device to relieve the pressure on both the tube and the shell sides of the heat exchangers. The molten salt discharge from the pressure relief device shall be directed to a safe area.

(d) Heat exchangers shall have a means to monitor, warn, and automatically shut down the system or bypass the exchanger when leaks are detected.

(e) Heat exchangers shall have a means of detecting leaks in the system. A pressure-sensing device shall be installed at a suitable location to detect an increase in pressure due to tube leakage.

(f) The shell side relief mechanism for shell, tube, and hairpin heat exchangers shall be designed to accommodate a single tube rupture.

(g) Insulation and heat tracing shall be used on the heat exchanger to reduce heat losses through the heat exchanger and prevent solidification of the molten salt.

(h) Heat exchangers shall be capable of being drained by gravity and located so that what is drained is directed into the molten salt tank or into the drainage tank required by para. 4.2.5(e)(3).

(i) Heat exchangers shall have an austenitic stainless steel nameplate permanently attached in such a manner that it is visible after insulation has been installed on the heat exchanger.

4.2.7 Instrumentation and Controls

(a) All required temperature, pressure, and flow measurement devices shall be selected based on their compatibility with the molten salt and the conditions

they will be subjected to during the operation of the system. Means shall be provided to protect these devices and prevent them from being affected by salt solidification and scaling or corrosion. All temperature, flow, and pressure instrumentation shall meet the provisions of the respective standard: ASME PTC 19.2, ASME PTC 19.3, or ASME PTC 19.5.

(b) The TES system shall have an audible alarm and visual indication at the energy storage control panel upon failure of any critical component.

(c) Controls shall be provided to safely shut down operations in the correct sequence. The designer shall consider the overall system design and any redundancies built into the system.

(d) The control system shall show the operational status of all controls.

4.2.8 Heat Trace

(a) Heat tracing systems shall be designed to withstand the design temperatures associated with the portion of the system on which they are installed.

(b) Heat tracing shall be installed in accordance with the manufacturer's instructions and IEEE 515 or any other nationally recognized standard.

5 CONSTRUCTION, INSTALLATION, AND COMMISSIONING

5.1 Molten Salt Storage System Construction and Installation

The requirements herein shall apply to the construction and installation of a molten salt system based on system components meeting the provisions of section 4 and the approved plans and specifications for the system.

5.1.1 Tanks and Tank Foundations

(a) Fabrication, erection, inspection, examination, and testing of molten salt storage tanks shall meet the requirements of API STD 620 or API STD 650, subject to the modifications and limitations regarding high temperatures indicated in this Standard.

(b) When the tank foundation is turned over to the tank manufacturer, the tank manufacturer shall check the foundation level and contour to ensure the foundation provided will properly support the tank before starting the work and shall notify the purchaser of any deficiency that might affect the quality of the finished work. Deficiencies shall be rectified.

5.1.2 Piping System Assembly, Testing, and Labeling

(a) All components associated with the piping system shall be assembled and sealed to prevent leakage.

(b) The assembled piping system shall be tested in accordance with either ASME B31.1 or ASME B31.3 as applicable based on the standard used for the piping system design.

(c) Connection protectors shall not be removed until immediately before the installation of the piping system components into the system.

5.1.3 Installation of Immersion Heaters

(a) All enclosures, seals, and joints between the immersion heater and the tank shall be assembled and sealed to prevent leakage. Threaded and flanged connections shall be protected against the entry of water or corrosive fluids.

(b) The immersion heater shall be grounded and shall be tested to ensure it is working properly.

(c) All electrical circuits shall be checked after installation to verify that they are in conformance with the heater wiring diagram and to ensure that all electrical connections are tight and that required clearances exist between live and electrical parts and live to ground.

(d) All required electrical protection shall be checked after installation to verify that it is in conformance with the approved electrical plans and specifications. All cables and glands shall be checked to ensure that they show no signs of damage and are adequate for the stated electrical duty.

(e) The heater terminal box shall be separated from the tank mating flange to ensure the terminal box temperature will not exceed the maximum allowable temperature specified by the box manufacturer. The air gap between the terminal box and immersion heater element flange shall not be lagged or closed off and shall provide free air circulation during operation.

(f) The immersion heater tube bundle shall be positioned and installed into the tank in a manner that provides the necessary clearance for the removal of the tube bundle from the tank for servicing purposes. When removed, a new gasket shall be applied between the tube bundle and the tank.

(g) The heating elements shall be installed in accordance with the manufacturer's installation instructions.

(h) The connection of the immersion heater assembly and the tank shall account for the expected thermal expansion and contraction between the heating elements and their support structures.

(i) Bolts used to connect the immersion heater with the tank mating flange shall be tightened in accordance with the immersion heater manufacturer's installation instructions.

(j) When immersion heaters are installed in areas where condensation occurs, an anticondensation heater shall be installed in the immersion heater terminal enclosure.

5.1.4 Installation and Testing of the Circulation Pumps

(a) The circulation pump manufacturer's recommended heat-up rate shall be confirmed prior to heating of the tank environment and ensured during the operation to heat up the tank environment. The rate of heating of the pump established by the pump manufacturer shall be followed when lowering the pump assembly into the tank containing molten salt or during heat-up operation.

(b) When installing the pump assembly into a preheated tank, caution shall be used when removing the tank cover to prevent personnel contact with heated exhaust gas. Pumps shall be installed in accordance with the manufacturer's instructions.

(c) When installing the pump assembly into a tank at ambient temperature, the depth of the storage tank shall be confirmed in relation to the location of the pump assembly prior to the installation.

(d) Piping and valves associated with the pumps shall be preheated to the system operating temperature before the pump is put into operation. Pumps shall be tested in accordance with the manufacturer's instructions and their operation within the limits provided by the manufacturer verified. After determining that all circulation pumps are installed properly, the pumps and all piping between the pumps, tank, and heat exchangers shall be brought up to the operating temperature of the system using heat tracing of the system or other approved means and maintained at that temperature until the remainder of the system is ready for initial operation.

(e) The first critical speed of the pump shall be a minimum of 25% above the pump nominal operating condition.

(f) Pumps shall have an operating speed range of 10% to 115% of nominal speed.

5.2 Commissioning

The TES system shall be commissioned prior to being placed in service in accordance with a TES commissioning plan that includes the following:

(a) a narrative description of the measures to be accomplished during each phase of commissioning, including the personnel designated to accomplish each of these measures

(b) a listing of the specific components, controls, and safety-related devices to be tested, a description of the tests to be performed, and the functions to be tested

(c) verification that required equipment and systems are installed in accordance with the approved plans and specifications

(d) testing of all associated protection systems

(e) training of facility operations and maintenance staff

5.2.1 Melting the Salt and Filling the Tank. The salt shall be melted and the tank filled in accordance with the provisions herein as a component of the commissioning process.

(a) The salts used in the system shall be heated to a temperature in accordance with the salt manufacturer's specifications. Ventilation and exhaust air in sufficient quantities to maintain air quality consistent with that in the ambient air surrounding the installation shall be provided when heating devices produce by-products of combustion. As salt is introduced into the tank, the temperature of the salts shall be maintained within the temperature range specified by the designer.

(b) During the filling process, the level of salt in the tank shall be monitored, and the temperature stratification throughout the tank shall be maintained within tolerances of the internal tank surface and salts in the tank as specified by the tank designer. Monitoring of temperature stratification shall be done in a manner agreed upon by the owner and the parties responsible for design, construction, and commissioning of the tanks.

(c) Systems that use nitrate salts shall take into consideration gas formation that will occur during the initial heating process. Vent piping shall be located to direct effluent gas from the melting system to a safe location away from personnel, areas of the system providing essential services, and other equipment, and in accordance with local environmental regulation.

(d) The melting system used shall be capable of removing insoluble solids from molten salt before the molten salt is put into the main storage tanks.

5.2.2 Initial Functional Performance and Acceptance Testing. The components of the TES system shall be evaluated for proper operation in accordance with the manufacturer's instructions and the commissioning plan prior to final approval.

5.2.3 Commissioning Report. A report describing the results of the system commissioning, including the results of the testing required by para. 5.2, shall be provided and retained as part of the project documentation.

5.2.4 Emergency Response Plan. The emergency response plan shall describe the emergency response procedures that are in place, including communication and interaction with owners of adjacent and potentially affected properties and local emergency response officials.

The emergency response plan shall be provided to the owner(s) or their authorized agent and the system operator before the system is put into operation.

6 INSPECTION, MAINTENANCE, AND OPERATION

6.1 General

After all equipment, components, and controls associated with the energy storage system are designed in accordance with section 4, and the entire system has been constructed, installed, tested, and commissioned as provided in section 5, the system and associated equipment, components, and controls shall be operated and maintained in accordance with this section.

6.1.1 Personal Protective Equipment. Personnel responsible for operation and maintenance and associated inspection and testing activities shall use appropriate personal protective equipment.

6.1.2 Personnel Training. All personnel involved in the operation and maintenance of the system or any portion of the system shall be trained for their job duties by the system owner or the owner's designated agent.

6.2 Inspection

6.2.1 Inspection Plans. Inspection plans shall be developed in accordance with ASME PCC-3, API RP 580, or other recognized good engineering practices and included in the maintenance manual required under para 6.3.

Piping inspections shall be performed in accordance with API RP 570. Tank inspections shall be performed in accordance with API STD 653. Pressure vessel inspections shall be performed in accordance with API 510 or NBBI NB23. These inspection plans shall provide the frequency of inspection as covered in para. 6.2.2. The inspection of specific components of the system shall be in accordance with para. 6.2.3.

Systems that monitor and protect the TES installation shall be inspected and tested in accordance with the manufacturer's instructions and the operating and maintenance manual. Inspection and testing reports with the results recorded shall be maintained in the operation and maintenance manual.

6.2.2 Inspection Frequency

(a) A daily inspection checklist shall be created from the requirements in the maintenance manual. The checklist shall include checks of liquid levels and areas to be examined for leaks or spills. A daily inspection log based on this checklist shall be maintained by those responsible for the operation of the system. The log must provide a way to fill in who conducted the inspection, the findings associated with the daily inspection, and any actions recommended and taken as a result of the daily inspection.

(b) Periodic and daily inspection checklists shall be compiled from the inspections plan. The checklists shall include inspection requirements for pumps, controls, heat tracing, electrical cabinets, insulation, and other equipment and components as described by the designer, manufacturer, or applicable regulations. A periodic inspection log based on the checklists shall be maintained by those responsible for the operation of the system. The log must provide a way to fill in who conducted the inspection, the findings associated with each periodic inspection, and any actions recommended and taken as a result of the periodic inspection.

6.2.3 Inspection of Parts of the System. The inspection of insulated parts of the system, immersion heaters, and heat exchangers shall be conducted in accordance with paras. 6.2.3.1 through 6.2.3.3 respectively, and included in the checklist required by para. 6.2.2(b).

6.2.3.1 When ultrasonic thickness checking is required by the inspection plan, the maximum temperature of the ultrasonic couplants during in-service NDT thickness gauging and corrosion mapping shall be determined and checked against the metal surface temperature. When the temperature of the test object is above the specified operating temperature range, the inspection of the part shall be delayed until the temperature of the object is reduced to within an acceptable range.

6.2.3.2 Immersion heaters shall be inspected at the frequency required in the specifications provided by the heater manufacturer and maintained in accordance with para. 6.4.6.

6.2.3.3 Heat exchangers shall be periodically inspected at the frequency required in the inspection plan and maintained in accordance with para. 6.4.7.

6.3 Operation and Maintenance

Operating and maintenance documentation shall be provided to the owner or the owner's authorized agent and to the system operator before the system is put into operation. This documentation shall include the sections and information described herein. The TES system shall be operated and maintained in accordance with this manual, which shall also include and retain a record of the operation and maintenance actions taken.

6.3.1 Operation

(a) A section covering the regular start-up of the system, including temperature profile of the system during start-up for heat exchangers, pumps, all piping, and associated valves and controls.

(b) A section covering the regular shutdown of the system, including temperature profile of the system during shutdown for heat exchangers, pumps, all piping, and associated valves and controls.

(c) A section covering the normal operation of the system, including

(1) standard operating procedures

(2) control set points