Guideline No. T-07(202502)

T-07

Alternative Fuel Heat Exchanger

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Foreword

The product inspection guideline of China Classification Society (hereinafter referred to as "CCS") specifies the applicable technical requirements and inspection and test requirements for classification products and authorized statutory products of ships to be approved/inspected by CCS.

The Guidelines allow users to adopt alternative test methods and requirements, provided they meet or exceed the standards set by the Guidelines.

The Guidelines are prepared and updated by CCS and published on http://www.ccs.org.cn. In case of any comments and suggestions, please contact CCS via service@ccs.org.cn.

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Main modifications in this version: None

Contents

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1 Scope of Application

The Guidelines are applicable to the approval and product inspection of marine heat exchangers for liquefied natural gas, alcohol fuel and ammonia fuel, including shell-and-tube heat exchangers and plate heat exchangers, as well as alternative fuel heat exchangers with a design temperature of -196°C ~ +200°C and a design pressure of not more than 16MPa.

2 Normative References

2.1 CCS *Rules for Classification of Sea-going Steel Ships*

2.2 CCS *Rules for Materials and Welding*

2.3 CCS *Rules for Construction and Equipment of Ships Carrying Liquefied Gases in Bulk*

2.4 International Code for the Construction and Equipment of Ships Carrying Liquefied Liquids in Bulk and its amendments

2.5 CCS *Rules for Natural Gas Fuel Used in Ships*

2.6 CCS *Guidelines for Ships Using Ammonia Fuel*

2.7 CCS *Guidelines for Ships Using Methanol/Ethanol Fuel*

2.8 CCS M03 *Heat Exchangers*

3 Terms and Definitions

The terms and definitions defined in the above survey basis are applicable to the Guidelines. For the convenience of preparation and use, the following definitions are directly quoted or supplemented in the Guidelines.

3.1 Heat exchange area: It refers to the total metal area in contact with cooling/heating/condensing medium.

3.2 Design pressure: It refers to the maximum pressure set for the heat exchanger, which is taken as the basic design load condition together with the corresponding design temperature, and its value shall not be lower than the working pressure.

3.3 Working pressure: It refers to the maximum pressure that the equipment may reach under normal conditions.

3.4 Design temperature: It refers to the metal temperature of a component set for a heat exchanger under normal working conditions. The design temperature, together with the design pressure, serves as a design load condition.

4 Drawings and Data

The following drawings and data shall be submitted for approval:

4.1 Drawings/data submitted for product drawing approval:

(1) List of product main performance specifications (including the product model, design pressure, design temperature, heat exchange area, working medium and materials of main parts of the products to be approved);

(2) General assembly drawing;

(3) Drawings of main parts and components: applicable contents such as shell (body), end cover, heat exchange tube, tube sheet, head, core assembly, heat exchange plate, clamping plate and clamping bolt;

(4) Design calculations (strength calculation and thermodynamic calculation (if necessary));

(5) List of physical and chemical properties of main parts and materials;

(6) Main process documents (heat exchange tube/tube sheet connection process, welding procedure and heat treatment, etc. (if applicable));

(7) Product instructions, nameplate and factory certificate sample (if it is used for international voyage ships, a bilingual version in Chinese and English should be provided).

4.2 Drawings/data submitted for approval:

(1) Factory overview: factory name, address, production history, production capacity, technical and inspection personnel, main products, affiliation, product trademarks, etc.;

(2) Details of the product to be approved;

(3) List of main production equipment;

(4) List of main testing equipment;

(5) Brief production process of the product to be approved;

(6) Quality management documents or quality system certificates;

(7) Enterprise registration certificate;

(8) Qualification certificate and/or production license, if applicable;

(9) Product quality certificate or sample of certificate;

(10) Quality control plan, if applicable;

(11) List of qualified suppliers, if applicable;

(12) Type test program.

5 Technical Requirements

5.1 Material requirements

5.1.1 The material of heat exchanger shall be selected with consideration given to the corrosivity and swelling property of fuel and to the suitability for its maximum working pressure and temperature. In addition to the requirements in the Guidelines, the material shall also meet the relevant requirements in the *Rules for Materials and Welding* and/or *Rules for Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk*, *Rules for Construction and Equipment of Ships Carrying Liquefied Gases in Bulk*, *Rules for Natural Gas Fuel Used in Ships* and other related

guidelines of CCS. If new steel is used, relevant data, e.g., a description of material compatibility, shall be submitted for approval. Additionally, special tests may be required if necessary.

5.1.2 The parts and components in contact with LNG shall be selected according to the relevant requirements in the *Rules for Construction and Equipment of Ships Carrying Liquefied Gases in Bulk*, *Rules for Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk* and *Rules for Natural Gas Fuel Used in Ships*.

5.1.3 For parts and components in contact with ammonia, materials susceptible to ammonia corrosion shall not be used, such as copper, copper-containing alloy, zinc, zinc-containing alloy, cadmium-containing and mercury-containing materials. Ammonia is an alkaline reducing agent, which can react with acids, halogens and oxidizing agents.

5.1.4 Materials sensitive to methanol, such as aluminum alloy, galvanized steel and lead alloy, shall not be used in systems containing methanol fuel. Materials sensitive to ethanol, such as zinc, aluminum, brass, lead and lead based alloy, shall not be used in systems containing ethanol fuel. Metallic materials that can be used include but are not limited to the following:

(1) Austenitic stainless steel;

(2) Duplex stainless steel, etc.

5.1.5 Ammonia may cause stress corrosion cracking in the fuel tank and pipeline system made of carbon-manganese steel or nickel steel. This risk shall be minimized by taking measures based on factors such as the selected materials and design conditions.

5.1.6 The carbon-manganese steel, if used, shall be fine grained. The nominal minimum yield strength shall not exceed 355 N/mm^2, and the actual yield strength shall not exceed 440 N/mm^2. For carbon-manganese steels with the steel grades of CL-II-2 and CL-III-2 and requiring PWHT for stress relief, one of the following structural or operational measures shall also be taken:

(1) Use lower strength material with a nominal minimum tensile strength

not exceeding 410 N/mm^2;

(2) Carry out PWHT for stress relief;

(3) Maintain the ammonia temperature preferably at its boiling point of -33°C, but not higher than -20°C;

(4) Ensure that water content in ammonia not less than 0.1%w/w.

5.1.7 If carbon-manganese steels with yield properties exceeding the limits specified in 5.1.6 are used, PWHT is required for stress relief.

5.1.8 Nickel steel containing more than 5% nickel and carbon-manganese steel not meeting the requirements in 5.1.6 and 5.1.7 shall not be used for ammonia heat exchangers.

5.1.9 If the ammonia fuel temperature meets the requirements in 5.1.6(3), nickel steels containing not more than 5% nickel may be used, such as nickel alloy steel with steel grades of 1.5Ni and 2.25Ni.

5.1.10 To minimize the risk of stress corrosion cracking caused by ammonia, measures shall be taken to keep the dissolved oxygen content in ammonia fuel below 2.5 ppm w/w.

5.1.11 For gaskets and seals of LNG heat exchangers, please refer to the relevant requirements in CCS *Rules for Construction and Equipment of Ships Carrying Liquefied Gases in Bulk* and in Part 2 of CCS *Rules for Materials and Welding*.

5.1.12 Gaskets and seals of ammonia fuel heat exchanger shall be made of metal, rubber, polymer and other materials compatible with ammonia, such as Metal wrapped gasket and PTFE.

5.1.13 Gaskets and seals of the methanol heat exchanger shall not be made of materials sensitive to methanol, such as nitrile rubber and butyl rubber. Polytetrafluoroethylene, ethylene propylene diene monomer (EPDM) and neoprene can be used instead. Gaskets and seals of the ethanol heat exchanger shall not be made of materials sensitive to ethanol, such as natural rubber, polyurethane, polyvinyl chloride, polyamide, methyl methacrylate plastic and polyester-bonded glass fiber

laminate. Nitrile rubber, neoprene, fluorinated rubber, polypropylene and thermosetting reinforced glass fiber can be used instead.

5.1.14 The Ω expansion joint of the shell-and-tube heat exchanger is generally bent with seamless pipe, its opening shall be greater than 15mm, and the height shall be greater than 1.6R. The wall thickness of the seamless pipe shall not be less than the minimum thickness calculated for shell strength (R - outer circle radius of seamless steel pipe).

5.1.15 The nominal thickness of the heat exchange plate of the plate heat exchanger shall not be less than 0.5mm, and the thinning amount of the plate forming shall not exceed 25% of the plate thickness.

5.2 Manufacturing requirements

5.2.1 The following issues shall be fully considered for low-temperature heat exchangers:

(1) The structure shall be as simple as possible to reduce constraints;

(2) Excessive temperature gradient shall be avoided as far as possible;

(3) The connection position between the nozzle and the shell shall have a smooth transition, and the inner wall at the end of the nozzle shall be rounded;

(4) The support or leg of the vessel shall not be directly welded on the shell, and a backing plate shall be provided.

5.2.2 For heat exchangers with unconventional/special design, the influence of low temperature and low stress shall be considered.

5.2.3 Ball-passing test

After the U-shaped pipe and coiled pipe are bent and shaped, steel balls with diameters specified in the following table shall be able to pass through the pipes smoothly.

Table 5.2.3 Ball-passing Test Requirements

r/d bending radius / pipe diameter	Pig diameter		r/d bending radius / pipe diameter	Pig diameter	
	No joint	With connectors		No joint	With connectors
2～3.5	0.70d	0.65d	＞5～10	0.85d	0.80d
＞3.5～5	0.75d	0.70d	＞10	0.90d	0.85d

5.3 Strength requirements

5.3.1 The strength of pressure-bearing parts (shell, tube plate, end cover, heat exchange tube, etc.) shall be calculated according to relevant provisions in Chapter 6, Part 3 of *the Rules for Classification of Sea-going Steel Ships* and related guidelines of CCS, or applicable standards accepted by CCS.

5.3.2 The strength of the connecting stub pipe on the heat exchanger shell shall be calculated according to relevant provisions in Chapter 2, Part 3 of the *Rules for Classification of Sea-going Steel Ships* and related guidelines of CCS.

5.3.3 The welding flange connection type on the heat exchanger shell shall meet the relevant requirements in Chapter 2, Part 3 of CCS *Rules for Classification of Sea-going Steel Ships*.

5.3.4 The opening and reinforcement on the heat exchanger shell shall be calculated according to relevant provisions in Chapter 6, Part 3 of CCS *Rules for Classification of Sea-going Steel Ships*.

5.3.5 The minimum thickness of the heat exchanger tube sheet shall not be less than 14mm.

5.3.6 For other types of heat exchangers, refer to CCS M03 *Heat Exchangers* and applicable standards.

5.4 Welding procedure qualification

If the heat exchanger is of welded structure, the welding procedure qualification and approval shall be carried out according to the *Rules for Construction and Equipment of Ships Carrying Liquefied Gases in Bulk and* the *Rules for Materials and Welding* of CCS and other standards accepted by CCS.

6 Raw Materials, Parts and Components

6.1 The raw materials, parts and components of products shall be controlled in

accordance with the relevant requirements of the current CCS rules. Raw materials, parts and components mainly include: shell, tube sheet, head, core assembly, heat exchange plate, clamping plate, clamping bolt, connecting stub pipe and other parts and components of heat exchangers.

6.2 For pressure parts and components such as shell, head and core assembly, 100% hydrostatic test shall be carried out before assembly.

6.3 If the parts and components mentioned in 6.1 are purchased, the applicant must take effective methods for monitoring subcontractor quality to ensure the quality, and must provide material quality certificates.

7 Type Test

7.1 Selection of typical samples

7.1.1 For initial approval, typical samples selected should adequately represent the heat exchanger to be approved in terms of the structural type, design pressure, design temperature, heat exchange area and medium. Generally, for each series of products to be approved, it is required to select one to two test prototypes with the maximum design pressure, the maximum heat exchange area and the median value of design pressure/heat exchange area respectively. If the performance range of the series is very narrow, it is allowed to only select one prototype with the maximum design pressure and one prototype with the maximum heat exchange area or only select one prototype with the maximum design pressure.

7.1.2 For re-approval, it is allowed to select only one model that is the most representative or has the highest market demand as the test prototype for each series of products.

7.2 Type test items

(1) Visual inspection

(2) Physical and chemical property test of raw materials for main parts and components

(3) Welding procedure qualification

(4) Test of welding test plate

(5) NDT

(6) Pressure test

(7) Leakage test

(8) Fluorescence inspection (if applicable)

(9) Dryness test (if applicable)

(10) Gas resistance test

7.3 Test methods and technical requirements

7.3.1 Visual inspection

The weld joint surface shall be visually inspected according to relevant standards and shall be free from defects such as crack, incomplete penetration, incomplete fusion, pore, arc crater, incomplete filling, slag inclusion and spatter. The transition between weld and base material shall be smooth. The shape of fillet weld shall be concave with smooth transition. The shell surface shall be ground into a smooth curved surface. Heat exchange tubes and machined pipe fittings and forgings shall be free from defects such as scarring, double skin and scratching.

7.3.2 Physical and chemical property test of raw materials for main parts and components

Important components such as heat exchanger shell, end cover, heat exchange tube/fin, tube sheet, clamping bolt and clamping plate shall undergo physical and chemical property test of raw materials, except that the purchased raw materials or castings are provided with CERTIFICATE OF MARINE PRODUCT issued by CCS. Heat exchange tubes shall be subject to the following tests:

(1) Flattening test: Flatten the tube until its inner surfaces touch each other. There shall be no damage or crack;

(2) Drift expanding test: Expand the outer diameter of the pipe end by 30% with a 45° angle punch. There shall be no damage or crack;

(3) Tensile test: Conduct this test on a universal material testing machine. The result shall not be lower than the value required in material standards.

7.3.3 Test of welding test plate

(1) Welding test plates shall be prepared for each heat exchanger. The size of the test plate, sample cutting, inspection items, test methods and acceptance criteria shall meet relevant requirements in Chapter 6, Part 3 of CCS *Rules for Construction and Equipment of Ships Carrying Liquefied Gases in Bulk* and in other applicable standards;

(2) Low-temperature Charpy V-notch impact test shall be carried out on the weld joint metal and heat affected zone of the product welding test plate. The temperature and acceptance criteria of the impact test shall meet relevant requirements in Chapter 6, Part 3 of CCS *Rules for Construction and Equipment of Ships Carrying Liquefied Gases in Bulk* and in other applicable standards;

(3) If temperature sections of the heat exchanger are made of different steels, product welding test plates shall be prepared separately.

7.3.4 NDT

Welds shall undergo NDT in accordance with applicable rules and guidelines or standards accepted by CCS.

7.3.5 Pressure test

All pressure chambers of the assembled heat exchanger shall undergo hydraulic test. The test pressure shall be 1.5 times the design pressure, and the test duration shall be 30 min. The test medium and method shall be in accordance with the standards accepted by CCS. During the hydraulic test, the heat exchanger shall be free from leakage, visible deformation or abnormal sound. The air pressure test, if used, shall be carried out according to standards accepted by CCS.

7.3.6 Leakage test

(1) The leakage test can only be carried out after the heat exchanger has passed the pressure test and all pressure chambers have been dried up

to standard. The test duration shall not be less than 15min;

(2) Leakage test includes air tightness test, ammonia leakage test, halogen leakage test and helium leakage test;

(3) Dry, oil-free and clean air, nitrogen or inert gas shall be used as the test medium for air tightness test;

(4) The air tightness test pressure should be the design pressure of the heat exchanger;

(5) During the test, the pressure shall be increased slowly to the specified pressure which shall then be kept for a sufficient duration. All weld joints shall be inspected for leakage. Small heat exchangers can be immersed in water for inspection;

(6) During the test, the heat exchanger is considered qualified if there is no leakage;

(7) Other requirements for the air tightness test shall be in accordance with relevant standards;

(8) A helium mass spectrometer shall be used for leakage detection, if so required in the design drawings of aluminum plate-fin heat exchangers. The leakage rate shall be calculated by the designer based on the technical parameter, working medium category, purity requirement and other information of the heat exchanger and marked on the design drawings. The leakage detection with helium mass spectrometer shall meet the following requirements:

① It shall be carried out after the heat exchanger is confirmed to meet the relevant strength, airtightness and drying requirements;

② The helium mass spectrometer leak detector with an appropriate precision shall be selected as the test equipment, and it shall be calibrated regularly using standard leakage holes;

③ The helium concentration shall not be lower than 20% during testing;

④ External leakage detection: Place the helium cover (which can be made of plastic film) over the workpiece under test; vent the air in the cover and fill it with helium; vacuumize the channel under test to the working vacuum degree of the instrument; determine the leakage value of the trace helium in the channel according to the reading of the helium mass spectrometer leak detector;

⑤ Internal leakage detection: Vacuumize the channel under test to the working vacuum degree of the instrument; fill helium into the adjacent channels of the channel under test at a pressure not lower than 0.1MPa; determine the leakage value of the trace helium in the channel according to the reading of the helium mass spectrometer leak detector;

⑥ The allowable leakage rate of heat exchanger shall meet the requirements of design drawings.

7.3.7 Fluorescence inspection (if applicable)

(1) This test shall be carried out, if specified in the design drawing of heat exchanger or in the contract;

(2) Ultraviolet light with a wavelength of 3200 A - 4000 A is used for fluorescence inspection on the heat exchanger surface, head and inner side of nozzle under the channel head.

7.3.8 Dryness test (if applicable)

(1) This test shall be carried out, if specified in the design drawing of heat exchanger or in the contract;

(2) The dryness test shall be carried out in accordance with Appendix H of NB/T47006.

7.3.9 Gas resistance test

This test shall be carried out for relevant channels of heat exchanger according to design drawings. The test conditions and requirements are specified in 7.7.4 of NBT47006. The allowable resistance difference of the heat exchanger shall be determined through calculation.

8 Unit/Batch Inspection

8.1 The inspection for issuing CERTIFICATE OF MARINE PRODUCT shall be conducted after the manufacturer has completed the required inspections/tests and the product has passed inspections/tests, reaching a deliverable state. The surveyor shall sample 5% from each batch/specification for inspection, with a minimum of one set in all cases.

8.2 Unit/batch inspection of products from manufacturers that have obtained CCS type approval

(1) Review of physical and chemical property test report of raw materials for main parts and components

(2) Visual inspection

(3) NDT

(4) Pressure test

(5) Leakage test

(6) Fluorescence inspection (if applicable)

(7) Dryness test (if applicable)

8.3 During the approval/inspection of heat exchangers, in addition to the requirements in the Guidelines, they shall also meet relevant requirements in Chapter 3, Part 1 of CCS *Rules for Classification of Sea-going Steel Ships*.