LR Marine bunker pipe systems

Single & Double wall piping for LNG Propulsion
**LNG as fuel for Ships**

The global shipping industry is facing challenges as International Marine Organization (IMO) has put in place restrictions on emissions from ships that has come into force in 2015 in the Emission Control Areas and 2020 for the rest of the world new. This legislation will significantly limit sulfur emissions from ships.

LNG is a potential solution for meeting these requirements - it has virtually no sulfur content, and its combustion produces low NOx compared to fuel oil and marine diesel oil. LNG is not only clean-burning, but may have economic advantages - on a calorific value basis even high Asian LNG prices are lower than global bunker fuel prices. As a result there have been recent developments to promote use of LNG as a bunker fuel.

Using LNG as fuel will require modifications to the ship. In some cases it is possible to modify the fuel system using the same engine so the modifications are on the fuel tank system and fuel delivery system.

The LR MARINE Pre Insulated pipe system has successfully been delivered for Cryogenic pipe Insulation on 50+ LNG vessels so using the same system for LNG propulsion was obvious.

The primary benefit of LR Marine pre-insulated piping systems compared to conventional Cryogenic pipe insulation is that the system is a 100% waterproof bonded system, with no carrier pipe movements within the insulation system and total elimination of water ingress and mechanical wear. Due to the “Sandwich” construction, the complexity and the number of pipe supports can be significantly reduced and the supports are placed directly on the insulation jacket. Approximately 90% of the insulation is done in the LR MARINE factory reducing onsite work to only very few joints.

During the last few years, LR marine has been very active on many projects, which is currently under investigation here in Scandinavia either as new builds or as conversion from Marine Diesel Oil to Natural Gas propulsion. For this application we have several products.

LR Marine has been working with different Engine suppliers and the number of different piping systems required for any given project depends very much on individual project specific location of LNG storage tanks and pipe routing to the Engines.
LR Marine remains to have its headquarters in Aalborg, Denmark, and operates various facilities from here. LR Marine also operates mobile production units for the execution of large orders in yards in China but can also serve the retrofit market in the rest of the world.
The piping for a LNG fuel system can roughly be broken into the following sections:

1. Insulated (cryogenic) LNG bunker pipe from the vessel’s propulsion station or manifold location to the LNG storage tank(s);
2. Insulated (cryogenic) LNG pipe from the tank to Evaporator
3. Gas pipe from evaporator the GVU (gas valve unit). Open deck pipe may be insulated
4. Gas pipe from GVI to engine
5. Vent pipes

If the piping is on open deck it will normally be single wall pipe but when the piping is located inside the hull of the ship rules according to IGC/IGF is that double wall pipe is required.

The gas piping system can be divided into 3 different types:

1. Single wall pre-insulated LNG Bunker pipe from vessel bunker location to LNG storage tank(s), piping between LNG storage tanks, piping from LNG storage tanks to evaporator(s) and venting pipes

2. Double wall pre-insulated pipe used for LNG or cold gas running inside the hull
3. Un-insulated double wall pipe used for ambient temperature gas running inside the hull; typically the pipes going to the GVU and from GVU to engines

Qualification

To qualify LR MARINE’s pre-insulated pipe systems for LNG applications, LR MARINE/LOGSTOR carried out an elaborate full scale test program at cryogenic temperatures.

The tests were made and documented by independent energy research institutes to verify the properties needed for the cryogenic application:

- The mechanical test and thermal properties mentioned above were tested and verified over the full temperature range.
- The materials were cycled between ambient and cryogenic temperatures to verify the bond strength between PUR and carrier pipe.
- A full-scale test of a 4” and 20” pre-insulated pipe loop cycled between -196°C and +65°C supported by FEM analyses.

The test proved that even when cycled between cryogenic temperatures and ambient no cracks appeared. The test also demonstrated that the systems remains bonded (foam is bonded to the service pipe.

While attempting to make the test conditions as realistic as possible the real test has been the conditions under which pipes being in service since 2001 has been exposed to. LR Marine has supplied pipe insulation for LNG carriers since 2001 and we have no had one single cold spot appearing.
Insulation system

- The pre-insulated straight pipes and components are insulated using a special cryogenic polyurethane foam insulation.
- The foaming propellant and the cell gas is a mixture of CO₂ and Cyclopentane. The material is completely free of CFC or HCFC. The ODP and the GWP is 0.
- The insulation material is developed and documented with the right combination of toughness and flexibility properties necessary for cryogenic application.
- The insulation is homogenous without substantial irregularities and it contains no foreign matter, which could lead to the formation of cold bridges.
- The insulation material fulfils the requirements of EN 253 at temperatures up to +140°C.
- It is specially formulated to meet the service requirements down to – 200°C.
- Polyurethane foam is a reaction product of polyols, isocyanate, catalysts, stabilizers and propellants.
- The foam is homogeneous with an average cell size of max. 0.5 mm.

Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Requirement</th>
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<tbody>
<tr>
<td>Density:</td>
<td>≥ 85+15% kg/m³</td>
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<tr>
<td>Closed cells:</td>
<td>≥ 88%</td>
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<tr>
<td>Water absorption if boiled:</td>
<td>≤ 10% (Vol)</td>
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<tr>
<td>Compressive strength 10% deformation (+23°C):</td>
<td>≥ 0.5 N/mm²</td>
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<tr>
<td>Compressive strength 10% deformation (-180°C):</td>
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<tr>
<td>Axial shear strength 23°C</td>
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<td>Tangential shear strength (+23°C):</td>
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<td>Thermal conductivity at +23°C:</td>
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<tr>
<td>Thermal conductivity at -180°C:</td>
<td>&lt; 0.013 W/m°C</td>
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<tr>
<td>Operating temperature:</td>
<td>-200°C to +120°C</td>
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The technical requirements are tested according to the EN 253, ISO 844, ASTM C 273, ISO 845, ASTM C 518 and ISO 4897.

The material parameters are subject to revision due to technical developments.
Casing material (HDPE)

The casing on the PRE-INSULATED PIPE system is extruded from black coloured High Density Polyethylene (HDPE). The HDPE materials used are chosen for their toughness and outstanding resistance against UV degradation, slow crack growth and rapid crack propagation. They are therefore well suited for service under as well tropical as arctic condition in a period exceeding 30 years.

Every pipe or fitting is delivered with a free media pipe end of 150-220mm. for welding. Casings in outer diameter up to 1400mm. are available.

Casing Joints/field joint kits

Jointing of the casing ends of every pipe and fitting is done using the acknowledged LR MARINE cross linked, heat shrinkable tubular casing joints. These joints possess the strength and rigidity which is crucial for a long and service free life of a system operating at cryogenic temperatures. They are 100% watertight and gastight.

The field joint kits are installed using a torch to make the crosslinked material shrink. The the cross link ratio is selected in such a way that the adhesives placed on the inside of the joint will melt and fully bond to the surface of the HDPE casing of the pipe. This will ensure the joints is 100% watertight.

Supports

PRE-INSULATED PIPE shall be supported on the outside of the casing. The system is so strong that the supports may be placed at will anywhere on the pipes.

The insulation and casing are so strong and creep resistant that the support plates may be held in practical dimensions and that the support distances are within common practice.

The PRE-INSULATED PIPE design with a strong bond between media pipe, insulation and casing ensures low deformation and low creep so that no voids or cavities are formed due to unavoidable small deformation at the supports, as is the case in conventionally insulated systems with staggered layers of half shells.
Figure 2: The picture shows FEM of the stresses at supports in a conventional DN 500 pipe left and PRE-INSULATED PIPE in two different insulation series at the right.

The axial shear strength of PRE-INSULATED PIPE between the media pipe and the casing is so high that it is advantageous to fix the support to the structure and let the pipe casing slide in the supports. The supreme abrasion resistance of the bimodal HDPE casing make it well suited for it, and experience shows that it is a technically and financially attractive alternative to the conventional clamped sliding supports.

LR MARINE supplies a complete range of supports in either galvanized or stainless steel. Supports designed for as well clamping as sliding are available in the program. The supports can be delivered designed for either standard or heavy-duty service.

**Service pipe material**

The service pipe selected is typically AISI 316L. This type of steel is selected because stainless steel is ductile even at cryogenic temperature. Should other material types be preferred LR Marine can fabricate all material types, including super duplex.

Wall thicknesses and classes can be selected according to individual requirements. But typically wall thickness is not bigger than schedule 10S per ASME B36.19-20.

The service pipe will be supplied with mill test certificate 3.1 and upgrade to 3.2 is possible.
**Type approval**

LR MARINE pipe insulation systems has standard type approval by DNV/GL, Lloyds and ABS for all applications on open deck and in cargo holds and we have recently conducted a series of tests to get system approval for this specific system applied for LNG Bunker pipelines inside vessels from Bunker station to LNG Storage tanks.

The LR Marine Bunker Line system has been applied and approved for the NB 87 M/S Stavangerfjord built at Bergen Group Fosen shipyard in Norway. The vessel started operation on July 14, 2013.

Responsibility of class Approval of individual propulsion systems lies with the shipyard but LR Marine shall obviously assist to gain necessary documentation to obtain approvals.

To obtain approval the piping system shall be well documented and the required documentation to get class approval can be obtained from LR Marine. The requirements may differ from one class society to another so you should contact LR Marine to assist with this well in advance.

**Class requirements**

- **Service pipe wall thickness**
  - The wall thickness is calculated through code requirements and depends on type of material and if the pipe is welded or seamless. This is an important point to note because seamless stainless steel pipes are both expensive and difficult to source so this must be agreed with classification company at early stage.

- **Service pipe routing in confined space**
  - When routing the pipe through confines space/hull the room must be vented with 30 air changes per hour or the pipe to be enclosed in a secondary conduit with air in between vented or pressurized using inert gas.

- **Service pipe joint method**
  - Only but welding is allowed. Flanges can be used where butt welding is not practical possible of units must be removed easily for maintenance.

- **Pressure rating of conduit piping**
  - Conduit carrying the service pipe shall have same pressure rating as the service pipe.

- **Stress analysis**
  - For pipes with design temperature lower than -110°C the pipe system must be analyzed using computerized stress analysis method. Practically that means most piping systems must be analyzed since there is a risk of having liquid gas (LNG) flowing through the pipe.

- **Ventilation**
  - Double wall pipes must be vented with 30 air changes per hour, alternatively the annulus can be pressurized using inert gas and equipped with a pressure sensor detection loss of pressure or increase of pressure.
Regardless what classification organization is used the requirements will be more or less identical since the requirements derives from IMO’s international gas codes (IGC & IGF).

This catalogue is not capable of mentioning all the requirements from IMO or class society but here are some important point listed:

- Service pipe material
  - Stainless steel is not directly mentioned but since this is the most commonly available material it is usually used for this type of pipes

- Service pipe qualification
  - The service pipe material (and conduit) requirements are clearly defined and the test requirements are also clearly define. The test requirements are too comprehensive to mention here but they will consist of
    - Impact test
    - Tensile strength
  - The testing may not be carried out at manufacturer’s laboratory so the time needed to get the material qualified should be considered. Some of the tests must be carried out at temperature lower than ambient and not all test facilities are having the equipment to do so.

**Pipe movement**

Stainless steel has a much higher coefficient of expansion or contraction when compared to carbon steel. When cooled down to cryogenic temperature of -165°C at which the LNG is typically stored the pipe will contract approximately 3 mm per meter of pipe, so if the total pipe length is 100 meter the total contraction will be 300 mm. When deciding the pipe routing this has to be taken into consideration to ensure the pipe is not over stressed.

The insulation provided by LR Marine is bonded the surface of the service pipe. So the insulation will follow the movements of the pipe even at cryogenic temperature. Combine with a high compressive strength of the foam this allows us to place the pipe supports directly on the jacket avoiding the typical high density inserts usually used for cryogenic pipe supports.

The double pipe system is non bonded allowing the service pipe free movement. To ensure the service pipe remains centered LR Marine has designed a special spacing system utilizing custom built springs. This will allow the pipe to move both in straight and

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Stress analysis

Once the routing of the pipe system is frozen LR Marine will conduct a stress analysis. Depending on class requirements typically only pipes with an operating temperature below -110°C requires a stress analysis.

Stress analysis is a finite element analysis breaking the pipe system into small elements and analyzing them one by one to determine the stresses and strains in the pipe as well as the pipe movements. To do so the system must be described in 3D and the external loads applied.

LR Marine is using Caesar II software to analyze the pipe system. The output is stress and strain in all defined nodes and the movement in the nodes. LR Marine will ensure that the stresses and strains are well within code requirements and we shall ensure the movements of the system are acceptable.

The first task to do is to made a 3D routing of the piping system

![Figure 3: typical 3D pipe routing](image)
Using the operating conditions agreed to with class society the analysis will identify areal with stress concentrations beyond the limits.
LR Marine will submit both the report from Caesar II as well as a summary of the results.

The analysis can take both temperature loads and accelerations (or movements) into consideration but the hydraulic modeling has to be carried out separately but this is not a class requirement.
According to IMO regulations “Gas fuel piping should not pass through accommodation spaces, service spaces, or control stations. Gas fuel piping may pass through or extend into other spaces provided they fulfill one of the following:

1. the gas fuel piping should be a double wall piping system with the gas fuel contained in the inner pipe. The space between the concentric pipes should be pressurized with inert gas at a pressure greater than the gas fuel pressure. Suitable alarms should be provided to indicate a loss of inert gas pressure between the pipes; or
2. the gas fuel piping should be installed within a ventilated pipe or duct. The air space between the gas fuel piping and inner wall of this pipe or duct should be equipped with mechanical exhaust ventilation having a capacity of at least 30 air changes per hour.”

LR Marine can fabricate the pipe system according to the preference of the client however the integration of alarm systems will not fall in our scope. The system can be delivered with branches to allow venting using inert gas or a system that can be pressurized with an inert gas and fitted with pressure sensors detecting loss of pressure.

But if venting is selected it should be taken into consideration that if the service pipe is operated at cryogenic temperature any moisture introduced through the venting will condensate and turn into ice.

Components description

The following section indicated the individual components in the piping system. However LR Marine does not supply the pipe system as “sticks and kits” but as a complete spool system. Using out vast experience we divide the system into spools to minimize the work at the shipyard and to reduce the risk of locking the pipe inappropriately. It is important that the pipe is allowed to move freely and the elbows allow this movement.

During installation LR Marine supervisor is overlooking the installation to ensure proper installation and that the components are placed in the right place.
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**Venting options**

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The following catalogue sections shows piping details and they are all based on PN10 pressure rating for both inner and outer pipe.

Typically, the outer pipe will have same pressure rating as the inner pipe even though the operating pressure may not be high. However, typically the class society will normally require the same pressure rating.

The wall thickness is calculated using the regulations set in IGF/IGC fCode from IMO.

For projects with 2-stroke engines pressure may be considerable higher and the wall thickness has to be calculated on a project specific base.

**Wall thickness & Pressure rating**

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**Straight pipe insulated single wall**

**Straight pipe insulated double wall**
Straight pipe un-insulated double wall

Elbow, 3D, 90°, insulated single wall
### Elbow, 3D, 90°, insulated double wall

![Elbow, 3D, 90°, insulated double wall](image1)

### Elbow, 3D, 90°, un-insulated double wall

![Elbow, 3D, 90°, un-insulated double wall](image2)

<table>
<thead>
<tr>
<th>DN (Inches)</th>
<th>OD (mm)</th>
<th>WT (mm)</th>
<th>OD (mm)</th>
<th>[W/m²°C]</th>
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</table>

Pipes can be supplied in 6 meter lengths. Other lengths available upon request. Wall thickness for service pipe may be project specific and selected to be thinner or thicker. The service pipe OD may also be supplied as metric.

Elbows have lengths of 1 by 1 meter. Other lengths available upon request. Wall thickness may be project specific and selected to be thinner or thicker. The pipe OD may also be supplied as metric.
**Reductions, concentric and eccentric, insulated single wall**

![Concentric reducer](image1.png)

![Eccentric reducer](image2.png)

**Reductions, concentric and eccentric, insulated double wall**

![Concentric reducer](image3.png)

![Eccentric reducer](image4.png)

**Reductions, concentric and eccentric, un-insulated double wall**

![Concentric reducer](image5.png)

![Eccentric reducer](image6.png)
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<th>DN</th>
<th>Inches</th>
<th>OD [mm]</th>
<th>WT [mm]</th>
<th>Weight per pcs. [kg]</th>
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</table>

Elbows have lengths of 1 by 1 meter. Other lengths available upon request. Wall thickness may be project specific and selected to be thinner or thicker. The pipe OD may also be supplied as metric.
Straight tee, un-insulated double wall

[Image of a straight tee, un-insulated double wall]

Joint kit insulated single wall pipe

The joint set consists of 1 pc. shrink joint, 2 pcs. shrink collars and 1 set of PUR insulation half shells.

Joint kit insulated double wall pipe

The joint set consists of 1 pc. shrink joint, 2 pcs. shrink collars, 1 set of PUR insulation half shells and a 200mm long set of halves from the conduit pipe.
Joint kit un-insulated double wall pipe

Cut part of conduit pipe, L=200mm and also cut in one place open longitudinally.

Pipe termination

Typical pipe termination for low temperature applications. May be altered on a project-to-project basis.

The Cryogenic End-cap is used to terminate the insulation and to eliminate water ingress and control the temperature in the heat shrink area. This may for example be at flanges and valves. The sealing between the pipe casing and the stainless steel end cap is made with a heat shrinkable end seal.

It is diffusion tight without further precautions. The Cryogenic End-cap may be used in direct sunlight and at ambient temperatures between −40°C and +80°C.
Bulk head penetrations

- Insulated double wall pipe, welded
- Insulated double wall pipe, Roxtec
- Insulated double wall pipe, welded
- Insulated double wall pipe, Roxtec
- Un-insulated double wall pipe, welded
- Un-insulated double wall pipe, Roxtec
Installation

Welding of service pipe and conduit
Both service pipe and conduit are normally made of stainless steel pipe. Even in sections where the service pipe is non cryogenic is the pipe selected as stainless steel to avoid any problems with contamination.

The welders of the pipe shall be qualified per EN 287 or similar project specific qualification procedure. The welder shall have a valid welding certificate covering all the sizes required and in the wall thicknesses used on the project.

Welding procedures shall be prepared and approved by classification society prior to installing the pipe system.

The pipes shall have backing gas during welding to avoid damaging the passive stainless steel surface.

NDT (non destructive testing)
The levels on NDT shall be determined by class society on the specific project but typically the service pipe welds will require 100% NDT and the secondary pipe shall have a minimum of 10% of the welds examined. Pressure testing may be required on both service pipe and secondary pipe.

All welds on spools supplied by LR Marine will have X-ray performed before delivery. If pressure testing is required, the service pipe will be pressure tested. It is not possible to pressure test the secondary pipe during fabrication so the pressure testing will be carried out as a part of the system test.

Pipe supports
The supports used for the insulated pipe shall be all stainless steel supports designed by LR Marine.

The supports for the un-insulated pipe shall be stainless steel supports. These can be standard supports clamped on the pipe but can also be supplied by LR Marine. If LR Marine is not supplying these the type selected shall follow the type indicated on the layout drawings (sliding/fixed type).