THERMAL ANALYSIS OF A MARINE LNG TANK

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ABSTRACT

The utilisation of natural gas as a source of energy is gaining popularity. Every year, new reserves are discovered, and there is now considerably more gas being discovered than is being consumed globally. Moreover, new sources are discovered about four times as much gas as it is consumed for every year. However, much of the world's gas reserves are spread out far from major consumption centres. As a result, gas transportation and storage are required. Liquifying the gas at cryogenic temperatures reduces its volume by more than 600 times, making storage and transportation much easier. In this study, thermal analyses were made on the LNG tank on a marine ship (TSR 18009) named "SELVÅG SENIOR" being constructed by SU Ship Design A.Ş. The analyses have been performed as transient-state and the results are projected for 5-day and 10-day time intervals.

Keywords: Heat flux, LNG tank, thermal analysis, transient-state.

1. INTRODUCTION

In the case of Liquefied Natural Gas (LNG), the temperature must be below -165°C (Rajani, 2021; TWI Global, 2021; UACJ, 2021; Vandebroek & Berghmans, 2012). Even though this condition is met, the fluid becomes liquefied. The LNG is reduced to around 1/600th of its volume as gas as a result of the cooling (Lun et al., 2014). The materials used in the containers that hold the gas at liquefaction temperatures must have a high level of ductility and fracture resistance while maintaining a high level of safety. In order to minimise the container's wall thickness, the material must also be strong enough to allow welding without risk of brittle fracture (Esab, 2001). Understanding the plant operations and the environmental conditions to which the plant will be exposed is the first stage in selecting construction materials. The following criteria are used to choose materials:

- The composition of the feed gas.
- Total installed cost - economic and practical concerns (buying, constructability, etc.).
- Temperature, pressure, velocity, pH, phase, dew point, and process fluid composition, including pollutants, at maximum typical operating conditions.
- Start-up, shut-down, and turbulence
- Steam-out operations and cyclic service.

Depending on the gas source, the following material degrading corrosion processes apply to LNG plants. Coal seam gas is typically pure, with the exception of a small amount of CO_2 (Fultz, 2014).

The material must also be able to weld without causing defects such as breakage Stainless steels can be used as they do not have a ductile/brittle transition temperature like aluminium and steels containing 9 per cent nickel. Aluminium and stainless steel have become uneconomical for large onshore tanks, but aluminium alloys are used for massive spherical tanks in gas tankers due to their lighter weight. At a reasonable price, 9 per cent nickel steel offers an appealing mix of characteristics. LNG tanks do not require a high level of corrosion protection (Mounce, n.d.; Rajani, 2021; Toussaint et al., 2013). A marine LNG tank and its cut view are shown in Figure 1.

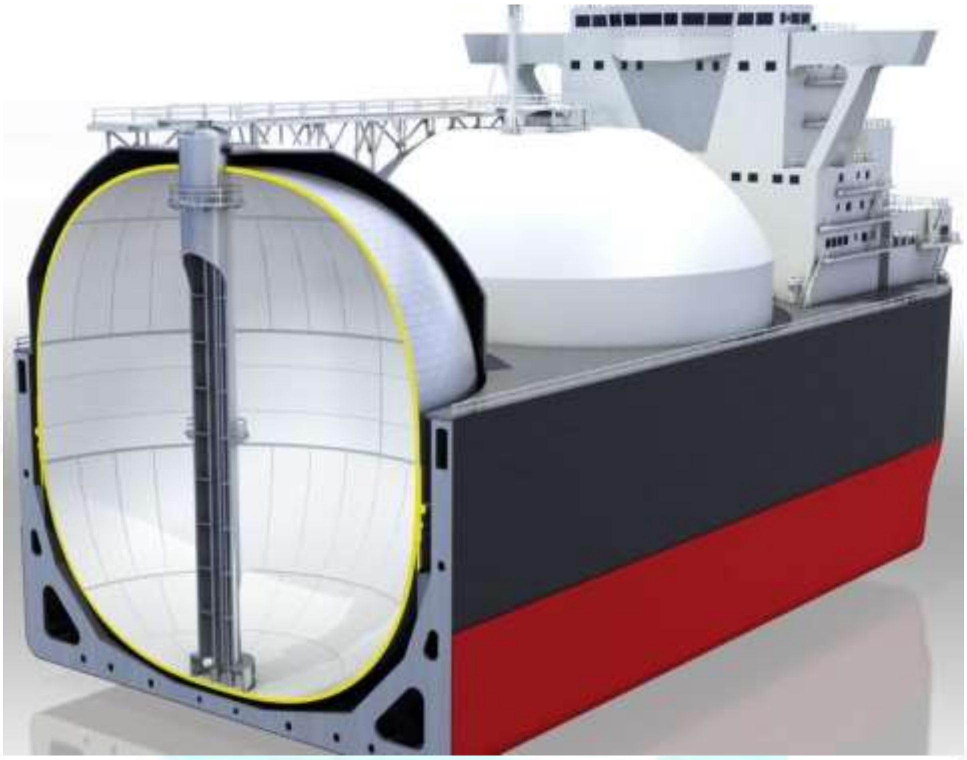

Figure 1. A marine LNG tank and its cut view (*DNV GL Approves KHI's New Non-Spherical LNG Tank - SAFETY4SEA*, 2017).

Nickel alloy steels are used in a variety of cryogenic applications because nickel improves hardenability and notch toughness at low temperatures. At temperatures below -50°C, steels containing 3.5 per cent, 5 per cent and 9 per cent nickel are utilised. The 9 per cent nickel steels are utilised at temperatures between -104°C and -196°C. The 9 per cent nickel steel was created in the early 1940s (Arup, 2017; Esab, 2001; Rajani, 2021). If the LNG is evaporated, it might form a dangerous gas cloud. Eventually, the gas cloud might ignite and result in a huge explosion (Balasubramaniyan, 2021; Rajani, 2021).

Since then, 9 per cent Ni has been the steel of choice for LNG tanks. Stainless steel containers are utilised for lower temperatures (liquid hydrogen - 252.8°C) (Rajani, 2021).

For LNG storage tanks, a novel low-nickel (6.0–7.5 per cent Ni) steel plate has been created with performance comparable to 9 per cent Ni steel, which has been utilised for decades. This outstanding performance, which is equivalent to 9 per cent Ni steel, was achieved by reducing the amount of nickel added, optimising the chemical composition, and applying the latest Thermo-mechanical controlled process technology to the steel plate, all of which contributed to cost and natural resource savings. Through cooperative research with customers and committees, developed steel has been put to practical use, and its uses are expanding (Kagaya et al., 2015). Companies that build storage and transportation tanks for LNG will need to acquire huge quantities of nickel stainless steel alloys as the sector grows (WATANABE et al., 2016). It's critical to work with a firm that is recognised for providing high-quality alloy metals. It is especially important in the case of LNG, as only the finest nickel alloys should be used to store natural gas in its liquefied state (Continental Steel & Tube Company, 2016).

The growing usage of LNG as a ship fuel provided that attention should be paid to the LNG supply chain and distribution network. Performing studies related with the behaviour of LNG tanks exposed to extreme heat sources is required for identifying potentially dangerous circumstances (Iannaccone et al., 2021). The heat distribution of maritime LNG fuel tanks is investigated using thermal transient finite element analysis modelling to predict the temperature distribution onboard LNG-fuelled ships (Grotle & Æsøy, 2018). In this study, transient-state thermal analyses of LNG tank were performed on a marine ship (TSR 18009) named "SELVÅG SENIOR" being constructed by SU Ship Design A.Ş. The numerical analyses have been considered time-dependent and performed for 5-day and 10-day time intervals.

2. MATERIALS AND METHODS

2.1. Materials

In this study, vertically positioned LNG tank on TSR 18009 ship designed by ''SU Ar-Ge Dizayn ve Mühendislik A.Ş.'' has been analysed. The LNG tank model which has a capacity of 350 m^3 in the front of the ship are given in Figure 2.

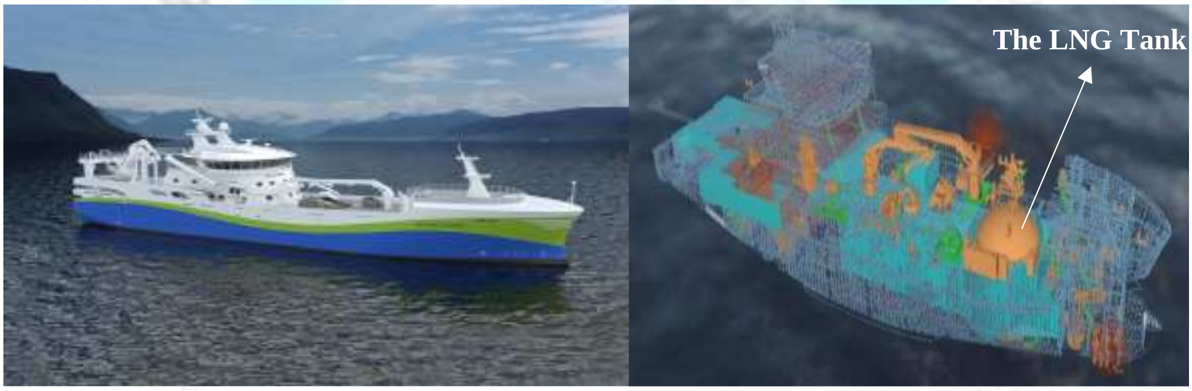

Figure 2. 3D model of the ship TSR 18009 and its interior design (*SU Ship Design*, n.d.).

Understanding the heat distribution on the LNG tank is critical for predicting the stress on the tank and its foundations. With double-walled insulated pipes, the fluid is filled into the tank at -165 degrees. As given in Figure 3, TSR 18009 ship's 3D LNG tank model has been created for thermal transient analysis with Ansys.

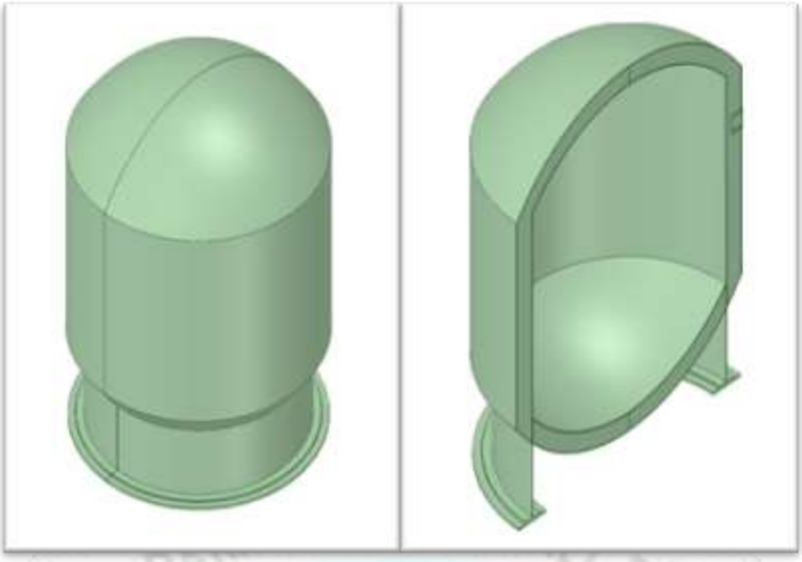

Figure 3. The 3D model of the LNG tank in TSR 18009 ship.

2.2. Methods

Ansys Thermal transient analysis has been used as the temperature distribution simulation program in the study. Thermal transient analysis with ANSYS shows a greater performance to capture the mean temperature distribution of complicated structures in nearly every complex situation. In boundary layers with high temperature dissipation, convection, and heat flow, it also performs well. Ansys placed control mechanisms such as orthogonal quality and skewness ratios for understanding the quality of the mesh. It is recommended the average skewness values to be between the range of 0.25-0.50 is a very good quality mesh. For the orthogonal quality that range reaches out to values of 0.20-0.69 and it is considered as good quality (Ansys Inc., 2011; GORGULU et al., 2021). The average mesh skewness in our situation is 0.36, while the average mesh orthogonal quality is 0.76. The simulation mesh contains 211,126 elements and 343,134 nodes. Liquefied natural gas at a temperature of 108 K enters the tank. The mesh structure of the LNG tank and the close-up view of section plot for epoxy support are given in the Figure 4.

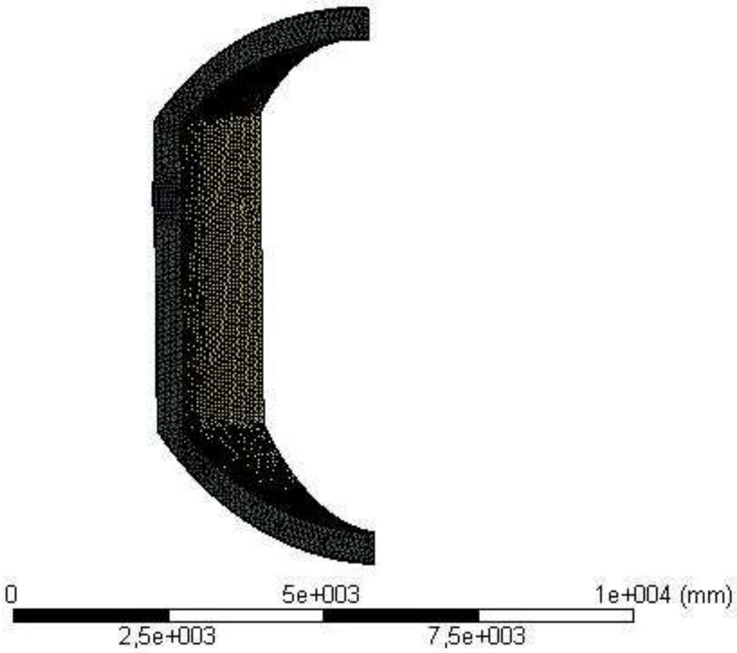

Figure 4. The mesh structure of the LNG tank and the close-up view of section plot for epoxy support.

Four insulation materials were used in the simulation on the LNG tank. The inner and outer layers are stainless steel, the second layer is perlite, and the support is epoxy and fiberglass wool. The property of relevant structure materials is provided by epoxy GRE supplier, perlite supplier together with relevant documentation and standard, refer to below Table 1.

Table 1. Thermal properties of the materials.

<table>
<tr><th colspan="2" rowspan="2">Thermal Properties</th><th colspan="2">304 Stainless Steel</th><th colspan="2">Epoxy GRE</th><th colspan="2">Perlite</th><th colspan="2">Fiberglass wool</th></tr>
<tr><th>20°C</th><th>-165°C</th><th>20°C</th><th>-165°C</th><th>20°C</th><th>-165°C</th><th>20°C</th><th>-165°C</th></tr>
<tr><td colspan="2">Density (kg/m^3)</td><td colspan="2">7910</td><td colspan="2">1750</td><td colspan="2">60</td><td colspan="2">20</td></tr>
<tr><td colspan="2">Specific Heat (J/kg.°C)</td><td colspan="2">460</td><td colspan="2">535</td><td colspan="2">753.74</td><td colspan="2">840</td></tr>
<tr><td rowspan="2">Thermal Conductivity (W/m.°C)</td><td>Layer direction</td><td rowspan="2">15.2</td><td rowspan="2">10.58</td><td>0.46</td><td>0.36</td><td colspan="2" rowspan="2">0.0237 (in atmosphere)</td><td colspan="2" rowspan="2">0.0236</td></tr>
<tr><td>Vertical direction</td><td>0.41</td><td>0.31</td></tr>
</table>

The temperature boundary conditions were defined for the inner and outer layers. The ambient temperature on the outside of the outer jacket is 5°C.

Additionally, convection heat transfer coefficient was applied to outer surface of outer jacket with the value of 5 W/m^2.°C. LNG temperature defined as -165°C at the inner surface of inner vessel. In order to reduce the calculation while ensure the reliability of calculation results, considering the structure feature of the tank, a partial model was built in this report, inner and outer shell, GRE support, perlite and skirt is included. Throughout the simulation, a transient and time-dependent solution has been utilised. The temperature distributions of the tank at the end of 10 and 15 days were calculated in the simulation.

3. RESULTS AND DISCUSSION

In this paper, a partial (1/6) model is built to reduce the calculation work. The model includes a section of 1/6 inner vessel and outer shell, the perlite and epoxy GRE support between them, and 1/6 skirt. The temperature distributions and convections through LNG tank were investigated as 3D by using comprehensive numerical model with Ansys. Temperature contours have been taken with a time 10 day and they are demonstrated in the Figure 5.

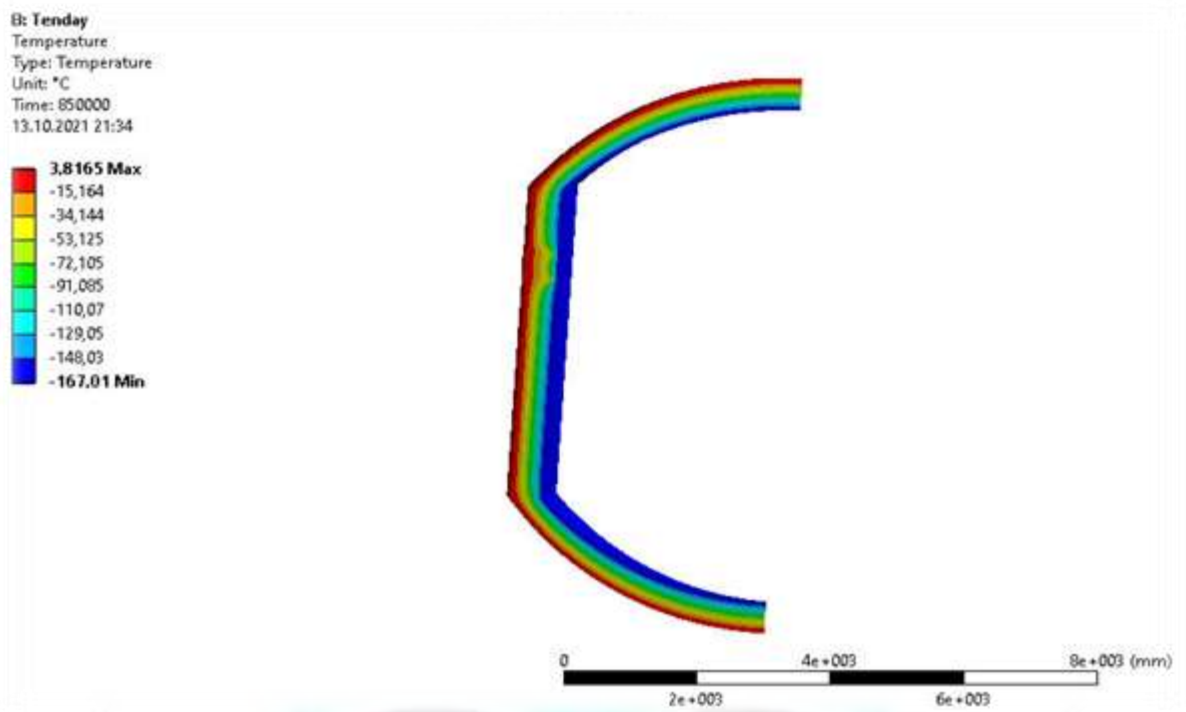

Figure 5. The temperature distribution on the 10^{th} day (°C).

According to Figure 5, the temperature decreases over time within 10 days, temperature changes in the boundary layer are seen. It is clear that the inner layer is mostly cooled in Figure 5. As proceeded to the outer, the temperature drops. The temperature values are changed between -167.01°C and 3.81°C. Heterogeneous contours draw attention throughout the tank thickness. This shows that the design can be further optimised in terms of temperature distribution. The table has been produced after the temperature distribution along the epoxy support was loaded from the software. The heat transfer may be a slow process, and reach a steady state in certain days. In order to study in how many days can low temperature causes effect to the outer jacket and 10 days (8.6×10^5 seconds) time is set in the calculation. After that, a 15-day (1.3×10^6 seconds) examination was carried out to evaluate how long the effects on the outer surface remained constant. Temperature contours have been taken with a time 15 day and they are demonstrated in the Figure 6.

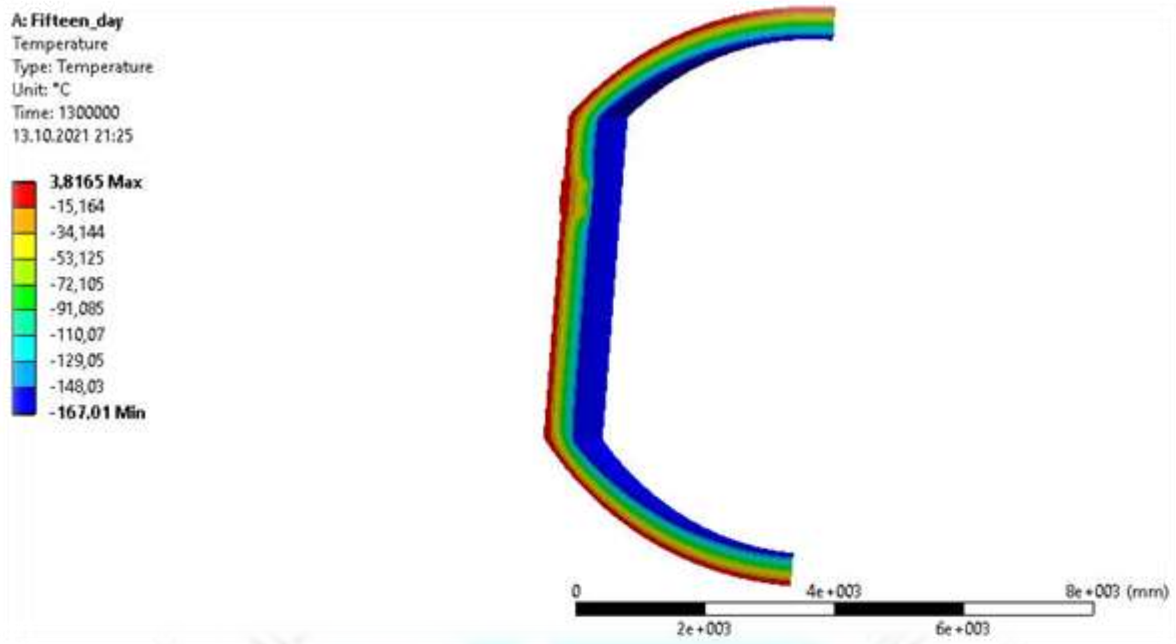

Figure 6. The temperature distribution on the 15th day (°C).

According to Figure 6., the temperature decreases over time within 15 days, it has been observed that there is a maximum difference of 1% in the 10-day and 15-day temperature contour charts. This 1% difference can be seen more clearly in the Figures 7 and 8.

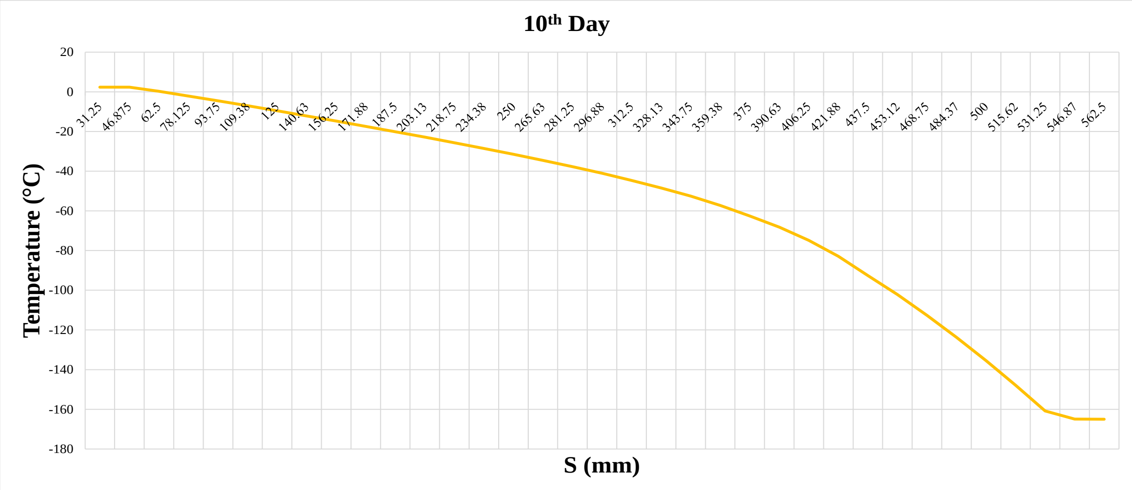

Figure 7. The temperature distribution with position on the 10th day.

The temperature and time figure depicts the temperature distribution from the vessel's outer surface to the inner surface during on the 10th day.

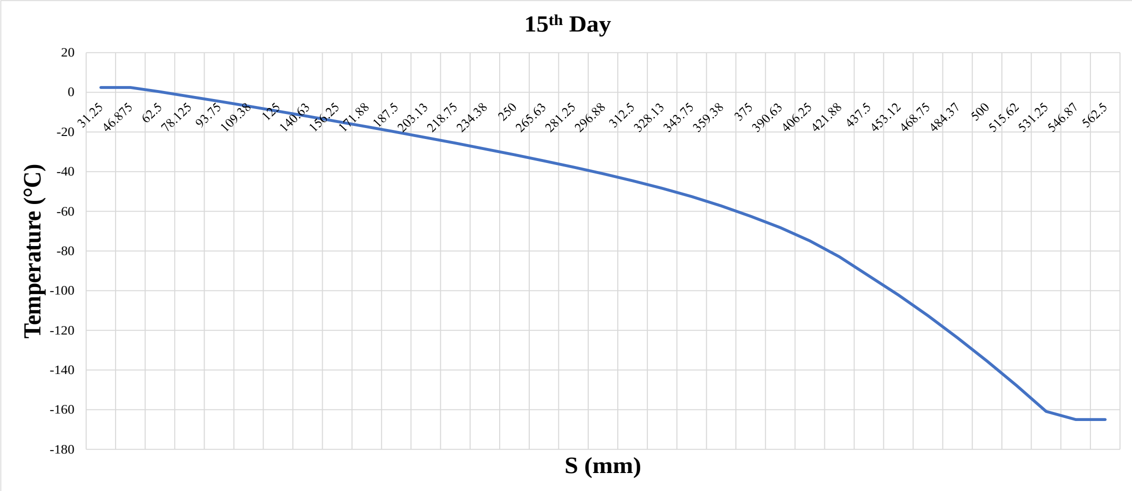

Figure 8. The temperature distribution with position on the 15th day.

The temperature and time figure depicts the temperature distribution from the vessel's outer surface to the inner surface during on the 15th day.

4. CONCLUSIONS AND RECOMMENDATIONS

In this study, thermal analyses were made on the LNG tank on a marine ship (TSR 18009) named "SELVÅG SENIOR" being constructed by SU Ship Design A.Ş. The analyses are time-dependent and the results are projected for 5-day and 10-day time intervals. The temperature values are changed between -167.7 °C and 3.8 °C. It is seen that there is a temperature change with a difference of 1% between the 10-day and 15-day thermal analysis. More effective results can be obtained by changing the insulation material and/or changing the thickness of the insulation material.

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