Transport of geothermal hot water in double hull product tanker

GeoHeat/ClimateWell

Grimstad/Abusdal, DNV proNavis
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Introduction

- Background
  - A potential Client has asked DNV for assistance with regards to an initial assessment of a transportation concept; shipping of geothermal hot water from Island to the Faroes. (Project provisionally referred to as "GeoHeat/ClimateWell project " or just "The Project" hereinafter.)
  - Main objective of the first phase is to have an initial assessment of the cooling effect during transport, or in other words to have a first rough feasibility assessment
  - Provided a positive outcome of the initial assessment, a proposal from DNV regarding further work and corporation will be required

- Initial response from DNV (this report):
  - A limited concept feasibility study for the ship transport concept as outlined
    - Study limited to hot water; same principles will apply for other liquids within reasonable temperature range (indicatively up to abt. 200 °C)
    - Please note that general hand calculations are applied, i.e. that the enclosed indications are not checked according to the applicable Class rules (DNV Rules for Ships, January 2013 Pt.3 Ch.1 Sec.14 STRUCTURES FOR HIGH TEMPERATURE CARGO)
      - Compliance with Class rules will require detailed analyses in the form of 3D finite element analyses
  - Outline of further process: DNV engagement and capabilities

Cooling effect in a Double Hull Product Tanker

Premises for analysis

- Assumptions:
  - Tank capacity based on an average Product Tanker in the range 20'-50' dwt
    - Approximately; 90 % of 42' dwt = 38' dwt
  - Route; Island – the Faroes apprx. 500 nm with sailing speed of 14 knots (based on the same average vessel) gives a sailing time of about 40 hours, included 10 % margin
  - Tank represented by a cylinder with length from the same average vessel; 150 m and diameter:
  - $V = DWT\rho_{water} = \frac{\pi d^2 L}{4} \Rightarrow d = \sqrt{\frac{4DWT*\rho_{water}}{\pi L}} \cong 18\,m$
  - Due to ballast and inspection needs the entire double hull is not available for insulation material and an inner tank is used
  - The tank configuration is therefore simplified as shown in the figure, with a long cylinder placed inside the hull with 50 mm Glass Wool as insulation material and 25 mm steel plates on each side
  - A conservative estimate is made, by assuming an ambient temperature of -20 °C
  - Further, the heat transfer is assumed as steady with no variation in time and one-dimensional because of the symmetrical properties of the cylindrical tank

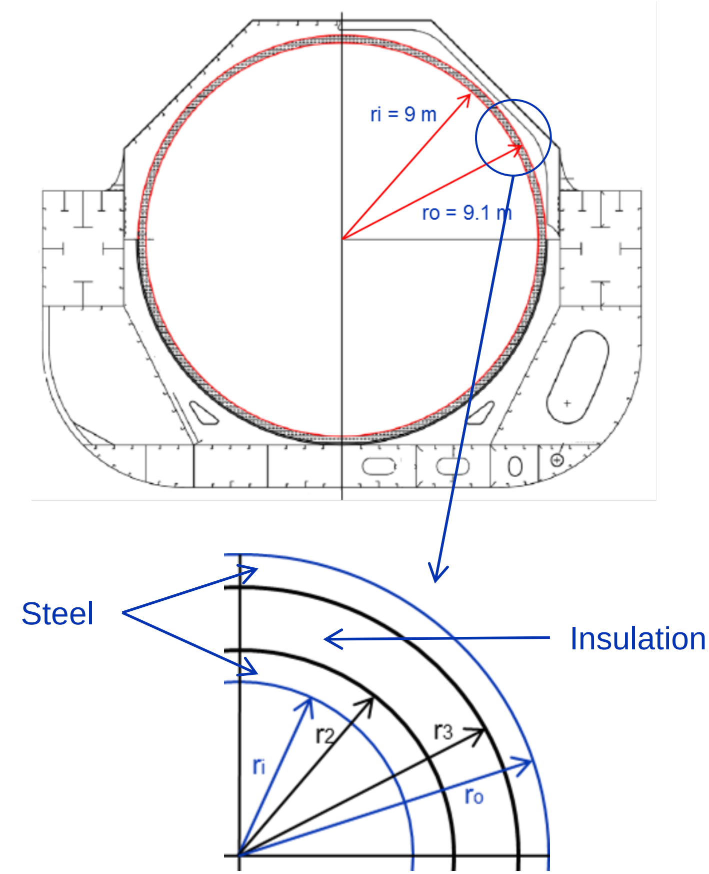

Figure shows a cross section of an installed cylindrical tank in the hold, used in calculation purposes only

Cooling effect in a Double Hull Product Tanker

Conditions and properties

- The following conditions and properties have been used in the heat loss calculations

Property		Value	Comment
Ambient temperature	θ_a	- 20 °C = 253 K	Conservative measure of still air temperature inside the hold
Cargo temperature	θ_s	95 °C = 368 K	Geothermal hot water
Heat transfer coefficient outside section	α_o	23 W/m^2*K	Conservative measure regarding heat transfer coefficient for still air
Heat transfer coefficient inside section	α_i	1000 W/m^2*K	Conservative measure regarding heat transfer coefficient for still water
Steel conductivity	λ_s	20 W/m*K	Source: Yunus A. Cengel (2006), *Heat and Mass Transfer*
Glass wool conductivity	λ_g	0.05 W/m*K	Source: Yunus A. Cengel (2006), *Heat and Mass Transfer*
End face	-	6 % addition	Taking into account the effects at the ends of the cylinder

- The following conditions and properties have been used in the temperature drop calculations

Property		Value	Comment
Volume of water in tanks	V_{water}	38,000 m^3	Based on capacity in an average product tanker (20'-50'dwt)
Heat capacity of water	$c_{p,water}$	4.21 kJ/kg*K	At 95 °C and atmospheric pressure
The Faroes (Reykjavik – Torshavn)	t_s	40 h = 144,000 s	500 nm at 14 knots and 10 % margin
The Netherlands (Reykjavik – Rotterdam)	t_s	*95 h = 340,000 s*	*1200 nm at 14 knots and 10 % margin*
Spain (Reykjavik – Bilbao)	t_s	*118 h = 425,000 s*	*1500 nm at 14 knots and 10 % margin*
Pump capacity		3000 m^3/h	Conservative measure regarding load and discharge capacity

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Analysis and results

- Heat loss through the insulated cylindrical section
- The thermal resistance network for this problem involves five resistances in series:
  - $R_i = \frac{1}{2\pi\alpha_i(r_i L + r_i^2)} \cong 0.0000001 \frac{K}{W}$
  - $R_{steel,i} = \frac{\ln\left(\frac{r_2}{r_i}\right)}{(2\pi L + end\ face)\lambda_s} \cong 0.0000001 \frac{K}{W}$
  - $R_{insulation} = \frac{\ln\left(\frac{r_3}{r_2}\right)}{(2\pi L + end\ face)\lambda_g} \cong 0.0001 \frac{K}{W}$
  - $R_{steel,o} = \frac{\ln\left(\frac{r_o}{r_3}\right)}{(2\pi L + end\ face)\lambda_s} \cong 0.0000001 \frac{K}{W}$
  - $R_o = \frac{1}{2\pi\alpha_o(r_o L + r_o^2)} \cong 0.000005 \frac{K}{W}$
- The steady rate of heat loss from the water becomes
  - $\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial\theta}{\partial r}\right) = Q \Rightarrow Q = \frac{\Delta\theta}{R_i + R_{steel,i} + R_{insulaiton} + R_{steel,o} + R_o} \cong 995\ kW$

- The temperature loss is then found by the first principle of thermodynamics, stating that the energy stored in a system can only be exchanged with the surroundings through heat
- Assumed; tank as stand alone system
  - $Q = m_{water} c_{p,water} \Delta\theta \Rightarrow \Delta\theta = \frac{Q}{V_{water}\rho_{water}c_{p,water}}$
  - $\Rightarrow \Delta\theta \cong 0.000006 \frac{°C}{s}$
- Total temperature drop then becomes a function of time
  - $\Rightarrow \Delta\theta_{tot} = \Delta\theta t_s$

Sailing leg	Distance	Temperature drop, transit
The Faroes	500 nm	0.9 °C
The Netherlands	*1200 nm*	*2.1 °C*
Spain	*1500 nm*	*2.6 °C*

- Including discharge time of 12 hours, (based on pump capacity)

Sailing leg	Distance	Temperature drop, total
The Faroes	500 nm	1.2 °C
Spain	*1500 nm*	*2.9 °C*

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Concluding remarks

- Based on the stated conservative simplifications the temperature drop is well within the estimations indicated by the Project of about 2°C
  - Calculations for other liquids could be provided if specifications of the fluid and operating temperatures are forwarded to DNV
  - Cargos above about 200°C will normally require independent cargo systems, i.e. tanks that are not integrated in the ship’s structure
- Cargo heating arrangements (waste heat from ME) not considered
- The calculations on the previous pages only consider heat loss related to the vessel, i.e. not any additional losses as a result of the loading and discharging operations
  - Calculations assume a 95°C temperature of water at the time of departure from Iceland: Initial heat loss from "cold tanks" is not included in the calculations
  - Effect of additional storage time (i.e. discharge time) on board is considered in indication of total temperature drop (prev. page, last table)
  - Heat loss in piping and connections regarding these operations will occur unless the system is pre-heated
- The effects of cargo handling and initial tank heating should be subject to more detailed scrutiny in the further investigations

Initial remarks on transport concept and vessel requirements

Comments from subject matter experts at DNV

- Vessel cross-section shown on previous pages and used for the initial verification is not necessarily representative for actual vessel design that would be ideal for this trade
  - Specifically, vessel shown is an LPG tanker, whereas a "standard" product tanker would most likely be better as a starting point in terms of total cost.
  - Heat loss in a "standard" product tanker will be somewhat higher, but as calculations are very conservative our conclusions should be valid also for any relevant double-hulled tanker
  - Heat loss (obviously) largely a function of insulation; as insulation is also a significant cost driver, the design should be carefully balanced in this respect
- Use of (converted) LNG tankers (as mentioned by the Client) will most likely not be feasible due a.o. to significant differences in specific gravity of LNG and water
  - LNG tanks are not designed for the loads that water cargo would entail
- Carriage of heated cargo is not particularly complicated – within reasonable limits
  - Standard DNV Class Rules exist and will apply
  - Level of tailor-made solutions, and thus expensive solutions, will be fairly limited
  - Nonetheless, the trade as indicated will probably require dedicated vessels, i.e. that capacity may not easily be taken from the charter market at short notice
- Please note that the choice of vessel or alternatively the design of a new vessel should be a result of a structured process considering the value chain or transport system in its entirety
  - The total efficiency of the concept may only be optimised if the logistics system is considered in a coherent process

Next stage: Discussions, further process

- DNV finds both the proposed concept and the Project in itself very interesting, and would very much like to pursue this opportunity together with the Client
- In this respect, we would like to highlight the following:
  - DNV will be able to contribute with advice and analysis services for more or less every possible aspect of a vessel, its systems or the transport solution in which it will operate
  - This also means that we can provide support and services throughout the entire lifetime of the project, all the way from the very initiation and early feasibility studies
- Instead of listing the totality of our potential service scope, DNV will be happy to engage in a discussion with the Project on how we could support and advance the process in the best possible fashion.

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