170K Arctic ARC7 Icebreaking LNG CARRIER

12th ASEF FORUM
2018. 10. 23.

Daewoo Shipbuilding & Marine Engineering, Co., Ltd.
Contents

- Northern Sea Route (NSR) and Arctic Resources
- YAMAL LNG Project & Arctic LNG Carrier
- Ice Trial
- Northern Sea Route (NSR) and Arctic Resources
Ice Extent in Recent 5 years

Arctic Sea Ice Extent
(Area of ocean with at least 15% sea ice)

Source: National Snow and Ice Data Center
Northern Sea Route (NSR)

- NSR is running through Kara, Laptev, East Siberian and Chukchi seas.
- Arctic environment is changed due to an effect of Greenhouse gas
  - Arctic ocean to be open to regular maritime traffic
- Increasing shipping demand for Northern Sea Route (NSR)
- Increasing resource development in Arctic area (Oil & Gas)
Advantages of using NSR

- NSR is attractive to shipping companies
  - Cut fuel consumption & CO2 emission

Main advantages
1. Reduced freight costs due to shorter distance and travel time:
   
<table>
<thead>
<tr>
<th>DISTANCE (NAUTICAL MILES)</th>
<th>TIME (DAYS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>20</td>
</tr>
<tr>
<td>200</td>
<td>33</td>
</tr>
</tbody>
</table>

2. Lack of sea piracy threat

Main disadvantages
1. Icebreaker guidance required
2. Crews have to be trained for operations in the Arctic
3. Short navigation period: 2-4 months per year
- **Approx. 61 large oil and natural gas fields** are located in the **Arctic Circle** in Russia, Alaska, Canada’s Northwest Territories, and Norway

- **43** of the 61 large Arctic fields are **located in Russia**

- **35** of these large Russian fields (33 natural gas and 2 oil) are located in the **West Siberian Basin**
Arctic Resources - Potential

Table 1: Arctic Mean Estimated Undiscovered Technically Recoverable, Conventional Oil and Natural Gas Resources by Arctic Province, Ranked by Total Oil Equivalent Resources

<table>
<thead>
<tr>
<th>USGS Petroleum Province Name</th>
<th>Crude Oil (billion barrels)</th>
<th>Natural Gas (trillion cubic feet)</th>
<th>Natural Gas Liquids 1/ (billion barrels)</th>
<th>Total Resources, Oil Equivalent 2/ (billion barrels)</th>
</tr>
</thead>
<tbody>
<tr>
<td>West Siberian Basin</td>
<td>3.66</td>
<td>651.50</td>
<td>20.33</td>
<td>132.57</td>
</tr>
<tr>
<td>Arctic Alaska</td>
<td>29.96</td>
<td>211.40</td>
<td>5.90</td>
<td>72.77</td>
</tr>
<tr>
<td>East Barents Basin</td>
<td>7.41</td>
<td>317.56</td>
<td>1.42</td>
<td>61.76</td>
</tr>
<tr>
<td>East Greenland Rift Basins</td>
<td>8.90</td>
<td>86.18</td>
<td>8.12</td>
<td>31.39</td>
</tr>
<tr>
<td>Yenisey-Khatanga Basin</td>
<td>5.58</td>
<td>99.96</td>
<td>2.68</td>
<td>24.92</td>
</tr>
<tr>
<td>Amerasia Basin</td>
<td>9.72</td>
<td>56.89</td>
<td>0.54</td>
<td>19.75</td>
</tr>
<tr>
<td>West Greenland-East Canada</td>
<td>7.27</td>
<td>51.82</td>
<td>1.15</td>
<td>17.06</td>
</tr>
<tr>
<td>Laptev Sea Shelf</td>
<td>3.12</td>
<td>32.56</td>
<td>0.87</td>
<td>9.41</td>
</tr>
<tr>
<td>Norwegian Margin</td>
<td>1.44</td>
<td>32.28</td>
<td>0.50</td>
<td>7.32</td>
</tr>
<tr>
<td>Barents Platform</td>
<td>2.06</td>
<td>26.22</td>
<td>0.28</td>
<td>6.70</td>
</tr>
<tr>
<td>Eurasia Basin</td>
<td>1.34</td>
<td>19.48</td>
<td>0.52</td>
<td>5.11</td>
</tr>
<tr>
<td>North Kara Basins and</td>
<td>1.81</td>
<td>14.97</td>
<td>0.39</td>
<td>4.69</td>
</tr>
<tr>
<td>Platforms</td>
<td>1.67</td>
<td>9.06</td>
<td>0.20</td>
<td>3.38</td>
</tr>
<tr>
<td>Timan-Pechora Basin</td>
<td>1.35</td>
<td>10.21</td>
<td>0.27</td>
<td>3.32</td>
</tr>
<tr>
<td>North Greenland Sheared</td>
<td>1.11</td>
<td>7.16</td>
<td>0.19</td>
<td>2.49</td>
</tr>
<tr>
<td>Margins</td>
<td>0.85</td>
<td>8.60</td>
<td>0.19</td>
<td>2.48</td>
</tr>
<tr>
<td>Lena-Amur Basin</td>
<td>1.91</td>
<td>2.11</td>
<td>0.06</td>
<td>2.32</td>
</tr>
<tr>
<td>North Chukchi-Wrangell</td>
<td>0.09</td>
<td>6.07</td>
<td>0.11</td>
<td>1.20</td>
</tr>
<tr>
<td>Foreland Basin</td>
<td>0.10</td>
<td>5.74</td>
<td>0.10</td>
<td>1.16</td>
</tr>
<tr>
<td>Vilinskii Basin</td>
<td>0.17</td>
<td>4.49</td>
<td>0.12</td>
<td>1.04</td>
</tr>
<tr>
<td>Lena-Vilyui Basin</td>
<td>0.38</td>
<td>1.34</td>
<td>0.04</td>
<td>0.64</td>
</tr>
<tr>
<td>Zyryanka Basin</td>
<td>0.05</td>
<td>1.51</td>
<td>0.04</td>
<td>0.34</td>
</tr>
<tr>
<td>East Siberian Sea Basin</td>
<td>0.02</td>
<td>0.62</td>
<td>0.01</td>
<td>0.13</td>
</tr>
<tr>
<td>Hope Basin</td>
<td>0.002</td>
<td>0.65</td>
<td>0.01</td>
<td>0.12</td>
</tr>
<tr>
<td>Northwest Canadian Interior Basins</td>
<td>0.02</td>
<td>0.31</td>
<td>0.02</td>
<td>0.09</td>
</tr>
</tbody>
</table>

Total 89.98 1,668.66 44.06 412.16


Note: Calculations may differ slightly due to rounding.

1/ Natural gas liquids are composed of ethane, propane, and butane.
2/ The USGS uses a natural gas to oil conversion factor in which 6 thousand cubic feet of natural gas equals 1 barrel of crude oil.
• YAMAL LNG Project & Arctic LNG Carrier
YAMAL LNG Project

1.3 TCM Yamal South-Tembey Field Resources Base

- 16 mtpa, LNG Production
- 1 mtpa, Condensate Production
- Drilling of more than 200 wells
- Construction of 3 LNG trains
- With 15 Icebreakers (LNG Carrier)
Design basis for Yamal Arctic LNG

<table>
<thead>
<tr>
<th>Principal Particulars</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Length O.A</td>
<td>299.0 m</td>
</tr>
<tr>
<td>Length B.P</td>
<td>283.1 m</td>
</tr>
<tr>
<td>Breadth, mld</td>
<td>50.0 m</td>
</tr>
<tr>
<td>Depth, mld</td>
<td>26.5 m</td>
</tr>
<tr>
<td>Designed draft</td>
<td>11.76 m</td>
</tr>
<tr>
<td>Cargo capacity</td>
<td>172,600 cbm</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Design concept</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Ice strengthening</td>
<td>Ice class Arc7</td>
</tr>
<tr>
<td>Service area</td>
<td>Sabetta ↔ Murmansk ↔ Europe/India</td>
</tr>
<tr>
<td></td>
<td>Sabetta ↔ NSR ↔ Korea/Japan</td>
</tr>
<tr>
<td>Independent navigation</td>
<td></td>
</tr>
<tr>
<td>Northern sea route</td>
<td>during summer/autumn</td>
</tr>
<tr>
<td>All year round</td>
<td>navigation in the Kara sea</td>
</tr>
</tbody>
</table>
**Design basis for Yamal Arctic LNG**

**Ice class (Arc7)**
- Summer / Autumn season: independent navigation
- Winter / Spring season: icebreaker escorted navigation may be required

<table>
<thead>
<tr>
<th>Ship category</th>
<th>Winter/spring navigation</th>
<th>Summer/autumn navigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arc4</td>
<td>Thin first-year</td>
<td>Medium first-year up to 0.9 m</td>
</tr>
<tr>
<td>Arc5</td>
<td>Medium first-year up to 0.8 m thick</td>
<td>Medium first-year</td>
</tr>
<tr>
<td>Arc6</td>
<td>Medium first-year</td>
<td>Thick first-year up to 1.5 m</td>
</tr>
<tr>
<td>Arc7</td>
<td>Thick first-year up to 1.8 m</td>
<td>Second-year</td>
</tr>
<tr>
<td>Arc8</td>
<td>Multi-year up to 3.4 m</td>
<td>Multi-year</td>
</tr>
<tr>
<td>Arc9</td>
<td>Multi-year</td>
<td>Multi-year</td>
</tr>
</tbody>
</table>

**Note:** The classification of ice adopted according to the "Sea Ice Nomenclature" of the World Meteorological Organization (WMO):

<table>
<thead>
<tr>
<th>Ice type</th>
<th>Ice thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multi-year</td>
<td>&gt; 3.0 m</td>
</tr>
<tr>
<td>Second-year</td>
<td>&gt; 2.0 m</td>
</tr>
<tr>
<td>Thick first-year</td>
<td>&gt; 1.2 m</td>
</tr>
<tr>
<td>Medium first-year</td>
<td>0.7 — 1.2 m</td>
</tr>
<tr>
<td>Thin first-year</td>
<td>&lt; 0.7 m</td>
</tr>
</tbody>
</table>
Overview
YAMAL Arctic LNGC Technologies

Ice Performance

- Double Acting System (DAS)
- Hull form development
  - Bow/Stern Ice Shape
  - Hull Form Optimization
  - Ice Hull Interaction

Winterization

- Heating & Thermal Insulation
- Semi-enclosed Mooring Spaces
- Anti-icing provisions
- Totally enclosed Bridge
- ER Cooling Water System

Arctic LNGC Key Design Characteristics

Strength & Safety

- Fwd. & Aft. Ice Belt
- LNG CCS in Ice condition
- Hull Load Monitoring
- ER Double Hull

POD Propulsion

- POD Hull Design
- POD Electric Solutions
YAMAL Arctic LNGC Technologies

Ice Performance
Extensive hull form development for **Double Acting System (DAS)** throughout various hull form alternatives

- 2 PODs & 1 Center Prop
- Ice Bow
- Moderate Ice Bow

VS.

- 3 PODs
- Bulbous Bow
- Optimized Ice Bow

**Open water & ice performance**
YAMAL Arctic LNGC Technologies

Ice Performance

Extensive researches and model tests
YAMAL Arctic LNGC Technologies

Ice Performance

Ice Performance

Maximum 2.1
YAMAL Arctic LNGC Technologies

Winterization
03. Winterization

- Totally Enclosed Bridge with Heated Glass
- Ice Detection Radar and Ice Searchlight
- Semi Enclosed Mooring Space
- Heating for Cargo Manifold Area / Fittings
- Semi Enclosed Space for Lifeboat
- Heating for Traffic System
- Anti-Icing for Safety System
- Heating for Essential Spaces
YAMAL Arctic LNGC Technologies

Winterization
POD Propulsion
World’s first/largest 15MW class Arc7 POD system

- Propulsion motor: 15,000 kW x 3 sets
- Propulsion frequency converter: Three(3) sets, one(1) for each propulsion motor
- Propulsion transformer: Six(6) sets, two(2) for each propulsion motor
- High voltage(6.6kV) main SWBD: 2sets
- Main generator(6.6kV): 11,250 kW x 4set + 8,450 kW x 2 sets
World’s first/largest 15MW class Arc7 POD system
Strength & Safety

- Ice region based on RS requirement
- In consideration of DAS (Double Acting System)

Forward Region

YAMAL Arctic LNGC Technologies

After Region
YAMAL Arctic LNGC Technologies

Strength & Safety

- Real time Hull Stress/Load monitoring by Ice breaking
  - Real time monitoring and log data.
  - Hull stress monitoring system + Ice load Monitoring
  - Sensor installation at Fwd, Amid, Aft
  - Fiber Optic sensor which are against Arctic Temperature
  - Monitoring of Navigation data(speed etc) and POD propulsion data(power etc)

*Diagram of sensor installation and data monitoring system.*
YAMAL Arctic LNGC Technologies

Strength & Safety

Hull Strengthening & Safety

Hull Strengthening against Ice Loads
YAMAL Arctic LNGC Technologies

LNG Cargo Containment System

Ice collision safety analysis for CCS in multiple scenarios
- FEA calculations with ice channel sides
- FEA calculations for shoulder loading in maneuvering in ice
- Iceberg collision
YAMAL Arctic LNGC Technologies

CCS flexibility in Ice/Arctic operation NO96
YAMAL ARC7 LNGC
ICE TRIAL
The Arctic Area for Ice Trial

- Ice Trials were carried out
  1. 2017. 02.18~03.08
     (CHRISTOPHE DE MARGERIE)
  2. 2018. 02.24~03.11
     (VLADIMIR RUSANOV)
The purpose of Ice Trial

Verification ship’s performance on ice field

Major demonstration items
- Speed performance (astern/ahead)
- Turning ability
- Vibration & Noise Measurement
- Function test of various equipment in Low Temperature
Flowchart of Ice Performance Trial

1. Ice Finding
2. The Measurement of Ice Characteristic
3. The Setting of Voyage Course for Ice Trial
4. The Measurement of Ship Speed & Power
5. The Correction of Measured Data

Result
- Speed Vs power
- Speed Vs ice thickness
- Power Vs ice thickness
Ice Finding

Find proper ice station to carry out Ice Trial
- SATELLITE IMAGE, ICE CHART
- INFORMATION FROM ICE BREAKER (ICE OBSERVER)
Ice Measurement (by AARI)

Measurement of ice properties
- ICE & SNOW THICKNESS MEASUREMENT, FLEXURAL STRENGTH
- ICE PROPERTY MEASUREMENT (ICE TEMP., DENSITY, SALINITY)
Ice Measurement (by AARI)
The Setting of Voyage Course for Ice Trial

- Judgment of Ice Thickness & Environmental condition
- Setting of Voyage Course
  - ICE & SNOW THICKNESS, ICE DRIFT
  - WATER DEPTH, WIND SPEED/DIRECTION
The Measurement of Ship Speed & Power

Ice Performance (Speed) Trial Measurement Plan (After trial)

- Start Point
- Power: Creeping, Increasing, 50%, Increasing, 100%, Decreasing, 75%, Decreasing, 25%
- Distance: +150m, +300m, +300m, +300m, +300m, +300m
- Position Number: ①, ②, ③, ④, ⑤, ⑥, ⑦, ⑧, ⑨, ⑩
- Measuring item:
  - Interval: 50m, 30m, 30m, 30m, 50m
  - Number of Measuring (Total 45):
    - ①: 5, ②: 11, ③: 11, ④: 11, ⑤: 7
- Symbol:
  - After Steady states
  - Ice & Snow thickness
  - Ice Strength (three point & ice temperature, salinity, density)
Ice Performance Test
The Correction of Measured Data

- Correct measured data & environmental condition to Requested (Contractual) condition.

- There is no standard Ice Correction Method in the world.

- Their own empirical method is used in Ice institute (ice model basin).

- Independent correction method for YAMAL LNGC was developed.

- The activities other than ice correction method such as managing and reporting were cooperated with HSVA.
Result (Speed-Power-Ice Thickness)

Table 2: Astern Performance raw data

<table>
<thead>
<tr>
<th>Test Run</th>
<th>H_ice [cm]</th>
<th>H_snow [cm]</th>
<th>SIG_F [kPa]</th>
<th>V_sog [kts]</th>
<th>P_tot [kW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run 20170223_1008_STL1As-1*</td>
<td>134.0</td>
<td>18.0</td>
<td>636</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Run 20170223_1008_STL1As-2</td>
<td>128.0</td>
<td>18.5</td>
<td>636</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Run 20170223_1008_STL1As-4</td>
<td>128.7</td>
<td>19.5</td>
<td>636</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Run 20170223_1008_STL1As-3</td>
<td>129.4</td>
<td>18.6</td>
<td>636</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3: Astern Performance corrected data

<table>
<thead>
<tr>
<th>Test Run</th>
<th>P_corr [kW]</th>
<th>V_ice [kts]</th>
<th>H_eq' [cm]</th>
<th>Average H_eq' adjustment</th>
<th>P_corr_av [kW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run 20170223_1008_STL1As-1*</td>
<td>145.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Run 20170223_1008_STL1As-2</td>
<td>140.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Run 20170223_1008_STL1As-4</td>
<td>141.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Run 20170223_1008_STL1As-3</td>
<td>141.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*The results of the creeping speed are only given for reference as the acceptance criteria for the constant speed is not fulfilled and insufficient ice measurements are available.

Figure 4: Astern Performance Test in 1.41m Eq. Level ice: Raw data and corrected data
Completion..!! World First ARC7 LNG CARRIER ICE TRIAL

CONGRATULATIONS!
SUCCESSFUL COMPLETION OF THE ICE TRIALS
FOR THE WORLD’S FIRST 172,600CBM ARC7 LNGC HAVING DSME HULL NO.2418
Thank You!

Wonseok Bae
wsbae@dsme.co.kr

Daewoo Shipbuilding & Marine Engineering, Co., Ltd.