LNG MIXING BEHAVIORS INCLUDING BUBBLES OBSERVED DURING THE BOTTOM FILLING OF HEAVIER LNG IN LNG MIXED STORAGE

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Background
The LNG market has expanded, and production sites, LNG specifications, etc., have rapidly become diversified in recent years.

LNG mixed storage technology provides great benefits, and enables safe storage of various types of LNG in a single tank.

LNG Mixed Storage Technology
In LNG mixed storage, it is necessary to avoid stratification which may cause rollover.

To promote mixing, depositing lighter LNG from the bottom of tanks and depositing heavier LNG from the top of tanks are the basic operations for filling storage tanks.

However, the above operations are not enough. Therefore, Tokyo Gas utilized a simulation technology to estimate ahead of time the LNG mixed storage performance of each tank.

Stratification & Rollover
Stratification is the formation of two or more layers in a tank due to differences in LNG density.

After stratification occurs, the lower layer is heated and its density decreases through the process of double convection. When density of the two layers becomes equal and the layers mix, the heat energy of the lower layer is released over a short period in the form of a large amount of boil-off gas (BOG), otherwise called ‘rollover.’

Observation Result: Unique Phenomenon
Tokyo Gas has succeeded in becoming the first in the world to visually observe and record a unique phenomenon in an LNG tank under operation. Heavier LNG from the bottom-filling nozzle:
- Moves against gravity to rise to the top
- Does not linger at the bottom
- Is mixed with bubbles

Conditions:
Under operation & when depositing heavier LNG from the bottom

LNG Tanker

Reception of LNG

Control unit

Cable reels

Camera

Conditions:
Under operation & when depositing heavier LNG from the bottom

Device:
Using the device developed by Tokyo Gas

Pick up area

Light

Camera

Observation of mixing behaviors:
Photos & Details

Bottom Nozzle
Photo A: Early stage of filling
Photo B: One hour after Photo A
Photo C: Several hours after Photo B

Fig. A: Schematic of Stratification and Rollover

LNG Tank Specifications
We selected an observation tank with a density meter, a jet-mixing device, etc., that can deal with the risk sufficiently. The following table shows the main specifications.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Specification</th>
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<tr>
<td>Capacity (m³)</td>
<td>135,000</td>
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<tr>
<td>Diameter (m)</td>
<td>94</td>
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<tr>
<td>Maximum liquid level (m)</td>
<td>40</td>
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<tr>
<td>Top-filling nozzle</td>
<td>Jet mixing device</td>
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<td>Yes</td>
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Discussion
(1) Rising of heavier LNG
Bubbles were observed being ejected from the bottom-filling nozzle with the deposited LNG. It is thought that the buoyancy of the injected LNG with bubbles lifts the heavier LNG as it is no longer heavier than the heel LNG.

(2) Cause of generated bubbles
Bubbles ejected from the bottom-filling nozzle with deposited LNG seem to consist of BOG partly generated due to flushing from heat input to the LNG through the cargo pumps, piping walls and so on. On the other hand, BOG was partly entrained through the funnel portion of the bottom-filling pipe.

(3) Amount of bubbles ejected from the nozzle
It was also observed that the amount of bubbles ejected from the filling nozzle decreased as time passed. It is thought that the bubbles collapsed due to head-pressure as the level of liquid in the tank became higher.

Observation Conditions
The observation of this unique and physically contradictory phenomenon was performed under conditions where heavier LNG was intentionally deposited from the bottom-filling nozzle.

To reduce the risk of stratification, the density-difference between the heel LNG and the LNG being deposited was set to 10 kg/m³ or less.

Observation Device
An internal observation device for LNG tanks, the only one in the world and developed by Tokyo Gas. This device made it possible to successfully observe and visually record the phenomenon.

For LNG2019, Tokyo Gas presents a new type of observation device.

Conclusions
The observation data will lead to a deeper understanding of the mixing mechanism when depositing heavier LNG from the bottom of storage tanks.

The obtained data will add tremendous benefits to LNG mixed storage technology:
- Increases the flexibility of LNG procurement and LNG tank operations.
- Contributes to decision-making for more effective utilization of existing LNG tanks without the construction of new facilities.

This detailed clarification of the mechanism and its application to a simulation model is now being researched by Tokyo Gas.

This achievement is expected to contribute to further growth of the LNG industry through use of simulation technology developed by Tokyo Gas.

Contact Us
Please contact us if you are interested in "mixed storage simulation" and the "tank internal observation device."